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FOREIGN TECHNOLOGY DIVISION

DEVELOPMENT OF ASTRONOMY IN THE USSR

(FIFTY YEARS OF SOVIET SCIENCE AND TECHNOLOGY)

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371

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FTD-MT-24-186-68-Vol I of II

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ABSTRACT

(U) The book offered here to the attention of the reader is intended to give a picture of the development of astronomy in the USSR in the 50 years since the great October Socialist Revolution. The book starts with two general sections which relate the organization of astronomical investigations in the USSR and the instrument equipment of Soviet astronomy. Subsequent sections examine stages and basic results of development in our country of astrometry and celestial mechanics; detailed characteristics of the development of our knowledge about the solar system and the closest and most important star for our life, the sun, is given; the evolution of the knowledge of stars and stellar systems is shown and finally age-old problems of cosmogony and cosmology agitating the human mind are examined. The book also illustrates new areas of astronomy bound to the development of physics and mechanics - radio astronomy and space study using rockets, artificial earth and lunar satellites, interplanetary automatic laboratories and spaceships. In conclusion research in the history of development of astronomy conducted in our country during the years of Soviet power is illustrated.

TABLE OF CONTENTS

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

PREFACE

The book offered here to the attention of the reader is intended to give a picture of the development of astronomy in the USSR in the 50 years since the Great October Socialist Revolution. During those years there were many quantitative and deep qualitative changes in our science and, in particular, in astronomy. Unconnected up to the revolution, depending in many respects on the initiative of the particular sides, research in astronomy during the years of Soviet power not only obtained the character of collective works, but also for the first time a specially created state organ, the Astronomical Council of the Academy of Sciences of the USSR began to be planned. New centers of astronomical investigations — observatories and numerous special astronomical stations — appeared in all the republics of our country. The number of astronomers-specialists increased tens of times. The huge army of amateur astronomers has burgeoned. Astronomical learnings have been widely propagandized in small circles at planetariums, in lectures, and also in an ever increasing number of popular books and pamphlets.

The book shows the successes and achievements of our astronomy and its considerable specific weight in the global astronomical science, and also those difficulties which it has had to overcome.

Before the eyes of our contemporaries the horizons of space boundlessly expanded; artifical celestial bodies are in the service of science; people — and among them the first Soviet person — have gone into space; the work of humanity has become a factor of space value.

The science of the sky especially needs international collaboration. In it unification of the efforts of scientists of different countries of our planet is dictated by the character of the object of investigation itself, and therefore for a long time astronomy has had an international character, and the international communications and collaboration in it are close and fruitful. They not only go to benefit science, but also are an important element in strengthening the peace and mutual understanding of peoples.

In the book the reader will find a series of descriptions which attempt to illustrate the development of the individual most important regions of astronomy. Certainly, it does not pretend to be an exhausting study of all questions of astronomy, its close contact with other natural and social sciences and its many-sided role in the infinite process of the knowledge and mastery of nature by man. However, in some measure the reader will find in the book a reflection of these problems. He will find those connections with questions of Weltanschauung, which from the most ancient times, were especially characteristic for astronomy.

The book starts with two general sections which relate the organization of astronomical investigations in the USSR and the instrument equipment of Soviet astronomy. Subsequent sections examine stages and basic results of development in our country of astrometry and celestial mechanics; detailed characteristics of the development of our knowledge about the solar system and the closest and most important star for our life, the sun is given; the evolution of the knowledge of stars and stellar systems is shown and finally age-old problems of cosmogony and cosmology agitating the human mind are examined. The book also illustrates new areas of astronomy bound to the development of physics and mechanics — radio astronomy and space study using rockets, artificial earth and lunar satellites, interplanetary automatic laboratories and spaceships. In conclusion research in the history of development of astronomy conducted in our country during the years of Soviet power is illustrated.

All questions are examined not only in a spirit of summing up, but also from the point of view of possible directions and prospects of the further development of astronomy. This is all the more so important and interesting that in many sections written by specialists in corresponding areas of astronomy, ideas are expressed whose development can essentially deepen our knowledge of the infinite Universe.

Each section of the book has a bibliography, which, while not pretending to be complete, nevertheless permits being oriented in literature on a given question.

In some degree astronomy interests everyone. This book is addressed to them, although it by no means belongs to the number of popular books. This scientific book is accessible, however, to sufficiently wide circles of readers. It is hoped that whoever, gazing into the night sky, has pondered the structure of the world, the forces and laws governing it, and the role and place of Humanity in the Universe, will find in this book much that is interesting and will again feel the surge of emotion which embraces a person in contact with the infinity of the Universe.

INTRODUCTION

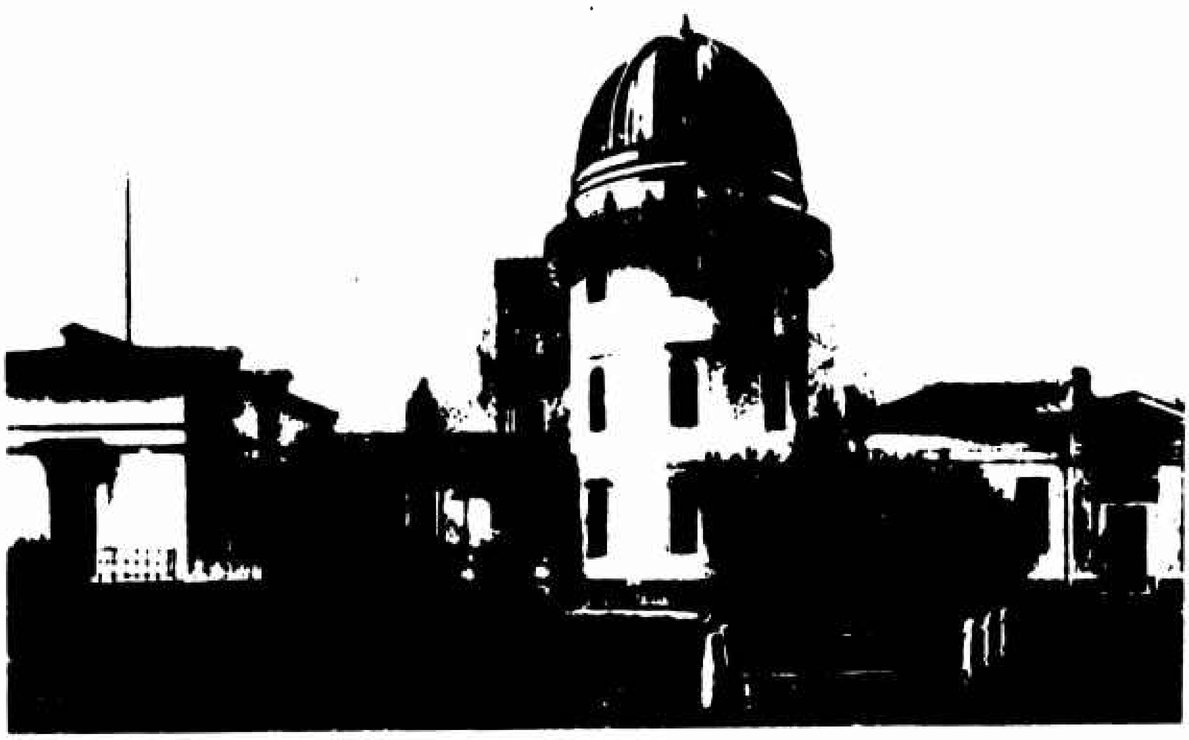
Prerevolutionary Russia had around ten astronomical observatories, among them the largest – of world importance – Pulkovo Observatory near Petersburg, founded in 1839. Several university observatories, the majority built in the 1820's and 1830's had a double assignment: ensure the teaching of astronomy, and conduct scientific work. They fulfilled these functions fairly well within the limits of their limited capabilities. These were the observatories in Derpt, Moscow, Petersburg, Kazan, Kharkov, Kiev, Odessa and others. Furthermore, there were still departmental observatories: in Nikolayev – the navy department and in Tashkent – the military. From 1899 to 1919 the International Latitude Station in Chardzhov operated, also located under the jurisdiction of the military department. All these observatories were well equipped with astrometric instruments for their time, but their very limited staffs usually consisted of the director – a professor of astronomy, an astronomer-observer and one or two assistants. In certain universities there were even assistant professors, occupied mainly with teaching.

Scientific work was conducted at the initiative of the director and reflected his interests, and to the honor of Russian astronomy it is necessary to say that these works in many cases were carried out on a high level. Thus, for example, in Derpt V. Ya. Struve measured the first star parallax, beating by a year V. Besselya in Koenigsberg, and made classical observations of binary stars; in Moscow B. Ya. Shveytser investigated the anomalous deflection of

a plumb line, later studied gravimetrically by P. K. Shternberg, F. A. Bredikhin developed theory of cometary forms, A. A. Belopc 'skiy began systematic observations of the sun, V. K. Tseraskiy and S. N. Blazhko discovered and investigated a series of new variables of stars; in Kazan heliometeric observations were conducted of the moon to study its rotation and libration, and M. A. Koval'skiy gave a method of detecting rotation of the Galaxy. Meridian observations for the determination of coordinates of the stars were being conducted in almost all university observatories, where a considerable part of the observations was used in composing fundamental catalogs of the stars. In this respect an especially voluminous work was carried out in Kazan and Gel'singfors on observation of stars of the large international catalog of the Astronomical society.

Pulkovo Observatory in 1911.

However, in spite of all the significance, these works frequently carried an episodical character, were conducted singly, and the selection of subject was determined by inclinations and taste of the authors. The only profitable exception was Pulkovo Observatory, distinguished by the purposefulness, sequence and volume of its



Moscow Observatory after reconstruction by
V. K. Tseraskiy in 1903.

works, basically thanks to the far-sighted plans of its organizer and first director V. Ya. Struve. Furthermore, inasmuch as this observatory was not a university, its colleagues were not distracted by the teaching of astronomy, if we do not consider the guidance of military geodesists and hydrographers (for them special small studios were created).

Returning to the position of Russian astronomy at the end of the past and beginning of the current century, it is necessary to note that its main deficiency was the separation of the investigations conducted in various observatories, inasmuch as there was no organ which would ensure an exchange of experience and the planning of scientific works even if in the most modest volume.

Scientific societies existing at that time could not improve the position. The most serious and respected of them was the Russian astronomical society in Petersburg, founded in 1890, at whose meetings were heard scientific reports both original and survey content. But it promoted only closer contact between astronomers and geodesists of the Petersburg establishments: the

university, Pulkovo Observatory, military and naval departments. This society issued the interesting "Izvestia." In 1908 the Moscow Circle of Amateur Astronomers appeared, renamed then into a society, which included almost exclusively Muscovites, mainly amateur astronomers, teachers, students and only two or three specialists from the university. The main merit of this society was that it gave young people, from which subsequently emerged a number of prominent specialists, a way of studying astronomy and conducting the simplest observations. In Lower Novgorod (now Gor'kiy) after the total solar eclipse of 1887, the Circle of Amateur Physicists and Astronomers was formed, issuing a yearly astronomical almanac, which was in great demand by amateur astronomers.

Engelhardt Astronomical Observatory (main building).

But all these societies were only a vent for the ripening tendency to closer and more constant scientific collaboration between the astronomical establishments of Russia and, being local, could not establish the desirable contact between them. In August, 1914, on the occasion of the 75th anniversary of Pulkovo Observatory in Petersburg a Congress of the International Astronomical Society was

held (Astronomische Gesellschaft)[1], which was in a position to establish a collaboration on an international scale, but which was disrupted by the exploding first world war.

Main building of the Nikolayev Observatory

In the summer of 1916 a group of Pulkovo astronomers dispatched by scientific colleagues of other observatories the project of convocation of an astronomical congress and a proposal for the establishment of a Society of Russian astronomers. This project obtained full approval of the majority of scientists, and in April, 1917, in spite of the difficult position with transportation and provisions in the country, the congress was called in Petrograd and attended by 64 representatives of almost all Russian observatories. At the congress, which was opened by the vice-president of the Academy of Sciences, Acad. A. P. Karpinskiy, it was decided to organize the Pan-Russian Astronomical Union; Prorector of Petrograd University A. A. Ivanov was made chairman.

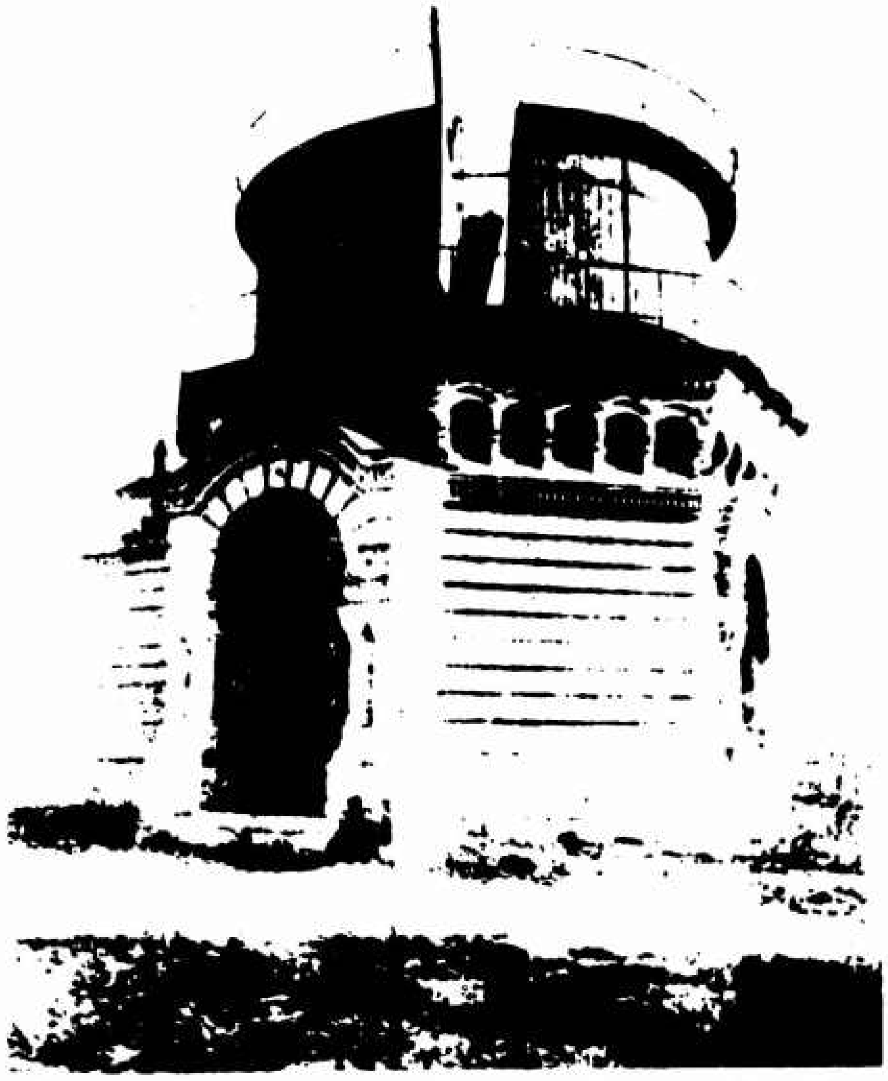
[1]This was the only national Astronomical society (created in Germany), which prior to the first world war conducted its work as an international organization. In the Council of the society an approximately identical number of German and foreign scientists had been selected; congresses of the society were held by turn in Germany and other countries.

In reports read at the congress many essential proposals were introduced for the organization of large cooperative works by forces of the Russian astronomical establishments, which due to economic difficulties, and then by civil war, unfortunately, remained long-unrealized.

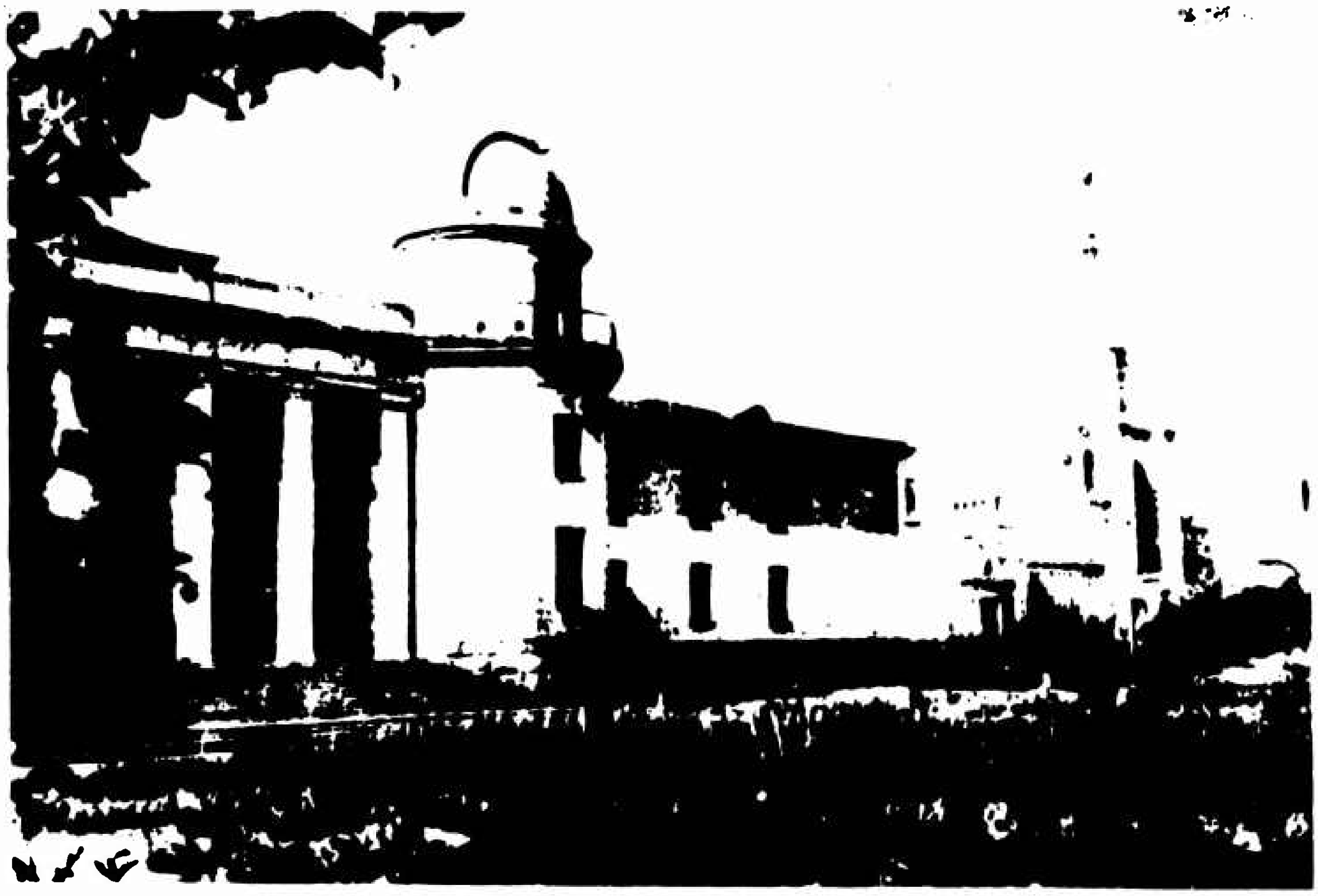
Subsequently this new scientific organization, from 1927 officially called the "Association of Astronomers of the RSFSR," held three more congresses: in 1920 at Petrograd, in 1924 at Moscow and in 1928 at Leningrad. Then its activity ceased, which, although it promoted the intercourse of astronomers of various observatories, still did not solve the basic problem – planning and coordination of investigations. Regarding other societies, in 1932 on the basis of the Russian Astronomical Society and The Moscow Society of Amateur Astronomers was formed the All-Union Astronomical and Geodesic Society, now existing in the Academy of Sciences of the USSR and counting over 30 republican, regional and municipal sections. Members of this society are specialists in astronomy, geodesy and cartography, and also persons interested in these sciences; it issues the "Byulleten'" ("Bulletin") and other publications, in particular timed to dates of solar eclipses visible in the USSR. From 1965 the society began to issue the popular science journal "Zemlya i Vselennaya" ("Earth and Universe").

However functions of coordination and planning the All-Union Astronomical and Geodesic Society naturally could not fulfill.

Meanwhile the need for this was sensed ever stronger and at the beginning of the 1930's the Astronomical Committee of People's Commissariat of Education of the RSFSR was established. The chairman was B. V. Numerov, director of the Calculating Institute, created in 1919 at Petrograd. The activity of this committee extended, however, only to those astronomical establishments of the RSFSR which belonged to the system of the People's Education. Besides corresponding university observatories and institutes, including the P. K. Shternberg Astronomical Institute formed in 1930 at


Tashkent Observatory (tower of normal astrograph).

Moscow, they also included the Pulkovo Observatory, which by regulations of 1862 went from the Academy of Sciences into the management of the Ministry of the Peoples' Education. But in 1934 the Pulkovo Observatory was again returned to the Academy of Sciences and turned out to be outside sphere of activity of this committee. It did not embrace the activity of observatories in the Union republics. Therefore in 1937 the Astronomical Council of the Academy of Sciences of the USSR was organized, in which was placed the planning and coordination of scientific research work in All-Union Scale. For more effective fulfillment of these functions in the Astronomical Council were created commissions for different directions of astronomical investigations, which regularly organize meetings and conferences. Furthermore, yearly, usually in January, the Astronomical Council conducts plenary sessions for



P. K. Shternberg State Astronomical Institute (GAISh. The new building on the Lenin hills in Moscow)

discussion of results of the past year and composition of plans for the coming year. Members of the Astronomical Council are the director of the most important astronomical establishments of the USSR and major specialists.

The sphere of activity of the Astronomical Council was still more expanded after the 1957 launching of the first artificial earth satellites, when the Council was assigned the organization of optical observations of these satellites over all USSR territory. The Astronomical Council is, furthermore, the Soviet National Committee in the International Astronomical Union (IAU), and thus represents Soviet astronomy in this international acientific organization.

In 1958 at Moscow the next, tenth congress of the International Astronomical Union took place, primarily prepared by the Astronomical Council.

Restored Pulkovo Observatory

The development of astronomy in great measure depends upon the degree to which the observatories are equipped with instruments. As already was noted, Russian observatories at the beginning of their activity were for that time not badly equipped; then observations were limited mainly to the area of astrometry.

Only the Pulkovo and partly the Moscow observatories were supplemented at the end of the past century by certain tools for research in stellar astronomy and astrophysics. Thus, prior to the advent of Soviet power our observatories were absolutely insufficiently unequipped for work in new rapidly developing areas of astronomical science.

In the first years of Soviet power the difficult position in the country did not permit essentially improving the instruments of our astronomical observatories. But already in 1924 in the Simeiz section of the Pulkovo Observatory a large reflector (diameter of mirror, 1 m) which was ordered even before the first world war in England, and with which subsequently G. A. Shayn and V. A. Al'bitskiy carried out outstanding work in stellar spectroscopy. Before the Patriotic War Pulkovo was enriched by the first large instrument built at Soviet plants – the large horizontal solar telescope designed by N. G. Ponomarev with D. D. Maksutov optics. The war inflicted hugh losses on Soviet astronomy; it suffices to say that the Pulkovo observatory and its Simeiz section were barbarically destroyed by fascists. Now not only are wounds healed, the destroyed observatories restored and expanded, but also several new observatories have been built: in Crimea, near Kiev, Erevan, Alma Ata, Shemakha, Tartu, not mentioning the observation stations such as the solar stationed near Kislovodsk, Alma Ata and Irkutsk, the latitudinal stations in Blogoneshchensk, Gor'kiy and certain others. Furthermore, even before the war a stellar-astronomical observatory was built in Abastumani and equipped with a 70 cm Makustov meniscus reflector with large objective prism.

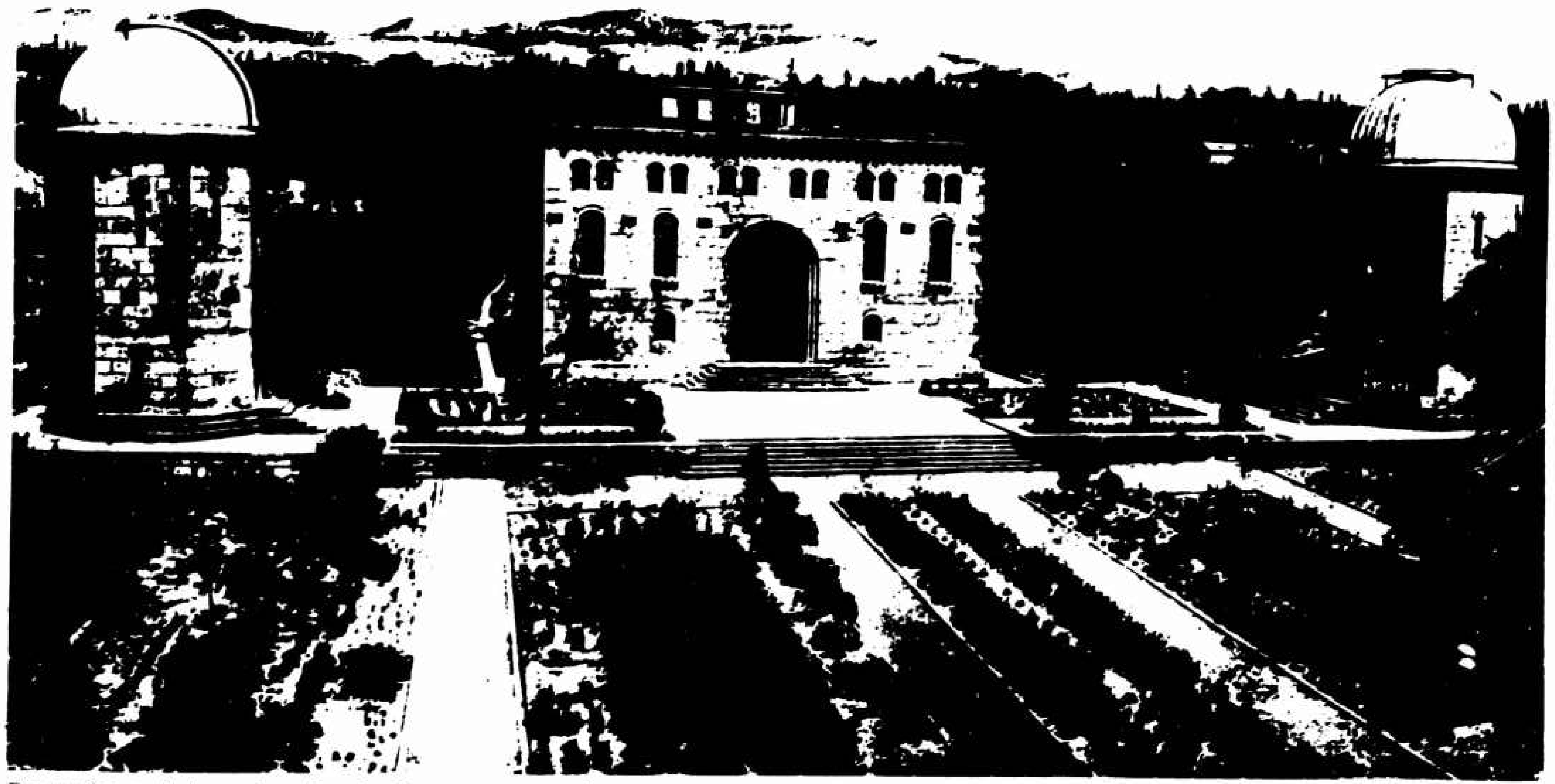
In prewar time an astronomical observatory in Dushanbe and an international latitudinal station in Kitab, were built, replacing the Chardou station which ceased operation in 1919.

Crimean Astrophysical Observatory (scientific settlement).

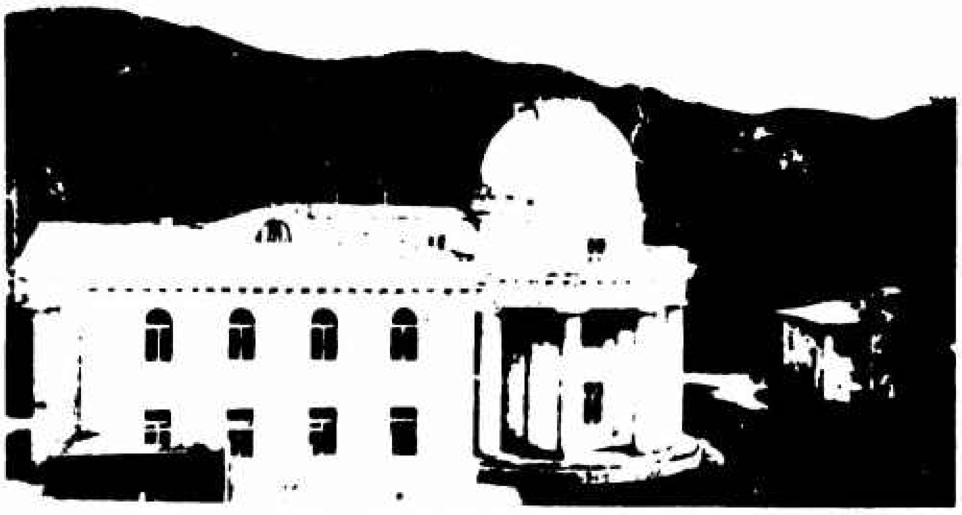
New Astronomical Observatory of the Academy of Sciences of the Estonian Soviet Socialist Republic (in Tyraver, near Tartu).

Recently the Byurakan Observatory of Academy of Sciences of the Armenian Soviet Socialist Republic received a Schmidt meter reflector; for the Shemakha observatory of the Academy of Sciences of the Azerbaydzhan Soviet Socialist Republic (in Pirkuli) a 70 cm meniscus telescope has been made and in the same place a 2-meter parabolic reflector has been set up. In the Crimean astrophysical observatory of the Academy of Sciences of USSR a large vertical solar telescope has long been in operation, and in 1960 a parabolic reflector with a 260 cm-diameter mirror was mounted – the largest in Europe and the third largest in world. In the very near future the same two instruments are designated for mounting in Armenia and in one of republics of Central Asia. At present domestic plants are working on the largest telescope in the world – a reflector with a 6 m-mirror diameter. It will be taken to the Northern Caucasus to the Special Astrophysical Observatory of the Academy of Sciences of the USSR. Thus, the former backward instrumentation in our observatories in considerable measure has already been overcome, and as regards the large telescopes now occupy an equal position among the most equipped observatories of other countries.

It remains to say concerning our scientific international communications. The biggest and most authoritative organization in astronomy is the International Astronomical Union (IAU), which every three years call an international congress. Nearly 200 Soviet astronomers are members of the IAU; around 12 are chairmen or deputy chairmen of permanent scientific commissions for various departments of astronomy; three were or are IAU vice-presidents (A. A. Mikhaylov, V. B. Kukarkin and A. B. Severnyy), and one is president (V. A. Ambartsumyan). As was mentioned above, the Xth IAU Congress, in which nearly 800 scientists from 35 countries participated took place in 1958 at Moscow. Already from this list one may see the considerable specific weight which Soviet astronomy has in world science.



Byurckan Astrophysical Observatory (general view of central part of the observatory from the south).



Astronomical Observatory in Abastumani
(Georgian Soviet Socialist Republic)

Solar mountain station near Kislovodsk

Extensive work is being conducted on general plans coordinated on an international scale, for example studies of the sun, in particular observations of the solar corona outside eclipses. Even before the second world war the Pulkovo Observatory advanced the project of composing the large "Catalog of Faint Stars," in the work on which seven Soviet observatories initially participated. In postwar years under IAU leadership observatories on five mainlands participated.

From 1957 close collaboration in optical observations of artificial celestial bodies was established, first of all with the socialist, and then and with certain capitalist countries, which promotes more precise determination of the motion of these bodies, and consequently, information about the gravitational field of the earth and properties of outer space. This important part of international collaboration is being carried out by the Astronomical Council of the Academy of Sciences of the USSR.

The most important foreign astronomers frequently visit Soviet observatories, where they present reports, participate in discussions of scientific questions and become acquainted with leading works. Soviet astronomers have also gone to other countries to participate in different symposia, conferences and commissions, and also to read lectures and for scientific work at the invitation of foreign establishments and by exchange agreements between science academies or universities. Especially close is scientific communications with the socialist countries, which frequently invite Soviet astronomers for consultations and the organization of joint investigations. Many young astronomers of socialist countries learn with us in post-graduate work, work on probation or do practical work.

Repeatedly Soviet expeditions go to other countries to observe solar eclipses. Thus, in 1927 Soviet astronomers participated in the observation of a total solar eclipse in the north of Sweden; in 1947 a large combined expedition went for this purpose to Brazil, in 1958 to the Chinese People's Republic, in 1962 to Mali, and in 1965 to the Kuka Islands (Polynesia).

Because of the vague knowledge of the southern stellar sky, in particular with respect to exact coordinates of stars, the Pulkovo observatory in 1962 organized an astrometric expedition to Chile, intended for several years. Colleagues of the expedition together with astronomers of the observatory at Santiago using the meridian instruments of the Chilean observatory and special new instruments made at the Pulkovo observatory and at the State optico-mechanical plant, observe the southern stars for more precise determination

of their positions and proper motions.

Besides this, Soviet astronomical establishments distribute their own publications in several hundreds of foreign observatories and institutes, obtaining in exchange numerous publications. In the United States an English translation regularly is printed of the "Astronomical Journal," published by Academy of Sciences of the USSR, and also a special journal wholly dedicated to reviewing the work of Soviet astronomers is published. Its editor for many years was the American astrophysicist O. L. Strube (1895-1963), great-grandson of the founder of the Pulkovo Observatory V. Ya. Strube.

Unification of efforts and exchange of results of investigations in astronomy are dictated by the e ience of the matter itself in ,articular the impossibility of embracing the whole celestial sphere by observations from the territory of one country. Furthermore, cooperation in investigation of rapidly occuring processes, for example, on the surface of the sun, permits (thanks to the rotation of the earth) conducting such observations continuously through a prolonged time. In connection with this astronomy has long since been the most international of all sciences, and international communications and collaboration in astronomy — the most close and fruitful. They not only benefit science, but also introduce their own mite to the common cause of strengthening peace and mutual understanding between peoples on our planet.

TOOLS AND INSTRUMENTS[1]

The quantity and quality of telescopes, their auxiliary equipment, climatic conditions of the location of observatories and, finally, organizational forms of the use of astronomical instruments in considerable measure determine the face of astronomy of a given country.

Talking about astronomical instruments, usually basic attention is on big telescopes used for astrophysical observations. This point of view is justified to a certain degree. Actually, the development of astronomical instrument making has given much to astrophysics. If in astrometry for determination of coordinates of celestial bodies and time it would not be possible to use successfully instruments from the middle 1800's, an astrophysicist observing with similar telescopes would appear comical to many. Apparently we deal here in the fact that principles of manufacture of astrometric instruments, simple in essence and comparatively small in size, were already known more than 100 years ago; they turned out to be so successfully embodied that every new step on the way to increasing the accuracy of astrometric measurements comes with very great labor.

Regarding astrophysical telescopes, the high-quality big reflectors, without which contemporary astrospectroscopy is inconceivable, appeared only at the beginning of the XXth Century. Naturally, they improved in time: their mirrors became larger and more exact, spectrographs, photographic plate and photoelectrical instruments were improved. This process continuously continues.

Why are big telescopes needed? By photographing the stars, clouds and planet it is possible to register even objects which are

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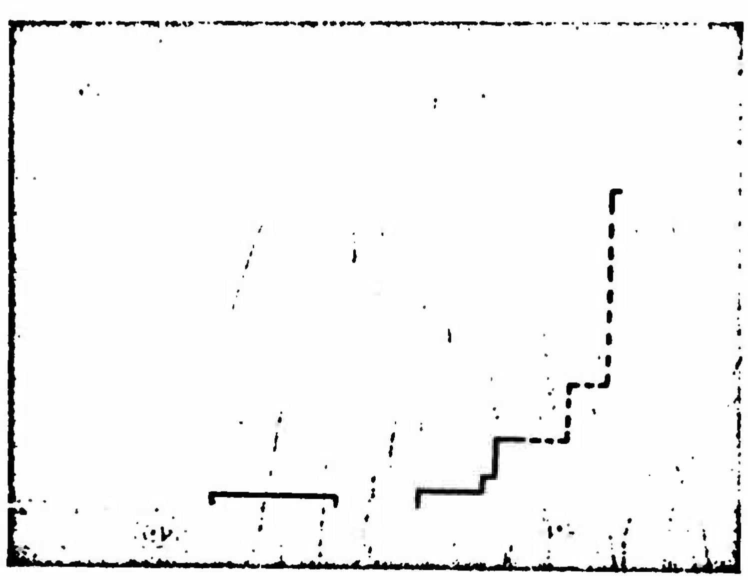
[1]For radio astronomical instruments see the section "Radio astronomy." The author gives his deep gratitude to V. B. Nikonov and N. N. Mikhel'son for very useful discussion of this section and a report of certain important historical facts.

very weak, hardly visible against the background of the glow of the earth's atmosphere, on comparatively small instruments 1-1.5 m in diameter. During spectral observations only a small part of light is in the particular spectral section. In order to increase the amount it is necessary to use a telescope of larger diameter. With confidence we can say that the contemporary picture of the surrounding universe is composed in considerable degree from spectroscopic observations on large telescopes.

Large reflectors are complex in manufacture and very expensive, constructed especially for astronomy.

The first large contemporary reflectors were built at the beginning of this century in the United States and Germany. Obtained results demanded still larger telescopes, and in 1917 at the Mount Wilson Observatory (United States, California) a 2.5-meter reflector was put into operation. In the 1930's in the U.S. several telescopes nearly 2 m in diameter were built, and in 1948 a 5-meter reflector at the Mount Palomar Observatory was completed. After this several reflectors from 1.5 to 3 m in diameter were built. The total area of mirrors of American telescopes larger than 1 m^2 at present is approximately 60 m^2.



Growth of the total area of objectives of Soviet telescopes with mirror diameter of more than 90 cm.

In England the first large telescopes were built in the 1930's. After the second world war several reflectors around 2 m in diameter were made there; they were taken to countries of the southern hemisphere. France has a 193-cm telescope built in 1958.

A contemporary reflector can be effectively used for approximately 50 years, but its spectrographs must be renovated every 10-15 years, and its electronics – every 5 years. Certain astronomers consider that to maintain a telescope in good condition 4% of its cost should be spent yearly on its modernization.

In Russia astronomical instruments were formerly never made. After the Great October Socialist Revolution our astronomy began to intensively develop. First of all, in the first 10-15 years the number of astronomers increased several times. The circle of investigated problems became wider, new areas began to develop, in particular astrophysics which in prerevolutionary time was studied only at the Pulkovo and Moscow Observatories. New astronomical establishments appeared, and of course required many new astronomical instruments.

Prior to the revolution Russia primarily obtained optical instruments abroad. In the beginning the young Soviet astronomy also had to do this.

In 1926 at the Simeiz Observatory (at that time a branch of the Pulkovo Observatory) a meter reflector, made in England, was installed. In skillful hands of V. A. Al'bitskiy and G. A. Shayn this instrument immediately worked effectively; it permitted obtaining much spectroscopic material, in particular on the radial velocities of stars.

The history of this tool is very interesting. In 1912 together with an 81-cm refractor it was ordered by the government from "Grebb Parsons" in England. At that time it would have been one of the largest telescopes in the world, exceeded only by two American

reflectors. After the revolution the efforts of L. B. Krasin renewed the order for the meter reflector and refractor, but the diameter of the refractor objective was increased to 102 cm. The firm refused to manufacture such an objective, and made only the mechanical part of the telescope. The order for the objective, again decreased to 81 cm, was then sent to the home optical instrument industry, which had appeared as a result of the industrialization of our country and the creation of a corresponding technical base. Fulfillment of this order played an important role in the development of our astronomical instrument making.

During the Great Patriotic War the meter reflector and mounting for the 81-cm refractor were destroyed.

In the 1920's Pulkovo Observatory obtained a zone astrograph and Littrov solar spectrograph. In all in this period not less than a million rubles' worth of astronomical instruments was purchased abroad. Besides the above telescopes Soviet observatories obtained transit instruments, instruments to measure astronomical photographs, universal instruments and gravimetric instruments.

Soviet astronomers of course understood that all this was insufficient, and planned the manufacture of bigger and better telescopes by domestic industry. They understood also the necessity of building in the southern part of the country a large alpine astrophysical observatory. This matter was taken up by the Leningrad Astronomical Institute, headed by its director, the talented astronomer B. V. Numerov whose wide spectrum of interests spread from celestial mechanics and gravimetry to astrophysics and astrophysics and astroinstrument making (B. V. Numerov, 1932).

Here is what Soviet astronomers A. V. Markov and V. B. Nikonov wrote in connection with this in 1932: "In 1929 the director of the Astronomical Institute B. V. Numerov visited all American observatories, including the mountain observatories in Arizona and Mount Wilson, and arrived at the conclusion that the most rational and efficient use of instruments... will be installation in one of the mountain regions of the south USSR, finding places which in

meteorological respects, number of clear days, etc., would approach American observatories (the Mount Wilson Observatory has 280 wo king days in a year). It has been decided to look for such a place, using the experience of Russian astronomers, who have earlier looked for a place for a mountain observatory, and also making astronomical observations in the mountains" (A. V. Markov, V. B. Nikonov, 1932).

At a conference of astronomers and geophysicists convoked during this time, it was decided to inspect several regions in the south of our country. In 1930 an expedition was sent to Nagorno-Karabakh; in 1931 Crimea, Aragats (Armenia), Osh (Ferganskaya valley), Borzhomi and Kakhetiya were inspected and in 1938 – Northern Caucasus, Svanetiya and certain other regions of Georgia. The search ended in 1932. Abastumani Observatory; it was intended to equip it with a large reflector, solar telescope and high-speed astrograph, but these plans were not carried out.

Besides the Abastumani Observatory observatories in Erevan and Dushanbe were organized in these years.

Workers of the State Institute of Optics (GOI) in Leningrad were interested in the manufacture of astronomical optics. To coordinate efforts in the manufacture of telescopes and other astronomical instruments the Commission of Astronomical Instrument Making was organized in 1931. It numbered colleagues from Pulkovo Observatory I. A. Balanovskiy (1885-1937), Ye. Ya. Perepelkin (1906-1937), B. V. Numerov (1891-1943), the designer of that institute N. G. Ponomarev (1891-1943). I. V. Grebenshchikov (1887-1953), V. P. Linnik, D. D. Maksutov (1896-1964), D. S. Rozhdestvenskiy (1876-1940) represented the GOI. V. V. Gavrilov worked on the commission and N. N. Kachalov headed it. The astronomical section was directed by B. V. Numerov.

One of the basic problems of the commission was organization of the manufacture of an 81-cm objective with a 900-cm focal length for the previously mentioned refractor of Pulkovo Observatory. The

home glass industry was presented a problem difficult for those times — preparation of disks of optical glass 85 cm in diameter and 10 cm thick for this objective. Through the commission orders passed also for the manufacture of optics for the great Pulkovo solar telescope.

Besides this, the commission studied the collection of wishes of astronomers, setting specifications and technical conditions on the manufacture of glass and long-term planning of astronomical instrument making. Here are some of the astronomical instruments whose manufacture this commission planned (see B. V. Numerov, 1932):

Reflector 150 cm in diameter	1
Reflectors 100 cm in diameter	2
Reflectors 60 cm in diameter	2
Reflectors 30 cm in diameter	3
Refractor 81 cm in diameter (termination)	1
Photographic refractor 50 cm in diameter	1
Long-distance spectrographs	3
Solar telescopes	2
Solar installations for observations of eclipses	5

Realization of this program would undoubtedly be an epochal event in our astronomy. However, at that time this program was apparently still insufficiently reinforced by the general level of development of our industry; furthermore, a series of prewar circumstances and then the war delayed its fulfillment. Nonetheless, in 1932 in the workshops of the Leningrad Astronomical Institute (organized in 1928) manufacture of a 30-cm reflector intended for the Abastumani Observatory was completed. For the eclipse of 1936 the Astronomical Institute prepared six so-called standard coronagraphs 10 cm in diameter with a focal length of 5 m; the State Optical Instrument Plant (GOMZ) made five caelostats; in 1941 the Pulkovo horizontal solar telescope designed by N. G. Ponomarev and built at the GOMZ began to operate.

In the observatory workshop during this time quite a lot of different instruments were built.

At Pulkovo spectrocomparators and chronographs were made; at the P. K. Shternberg Joint State Astronomical Institute (OGAISh — now GAISh) gravimetric instruments and different photometers were being built.

Equipment of Soviet observatories was supplemented also by imported instruments. Observatories connected with determination of time, obtained eight models of the Short clock and also transit instruments from the German firm "Askanie-Werke" with an objective diameter of 100 mm. American spectrohelioscopes were placed at solar survey observatories.

A great role in the development of domestic telescope manufacture was played by the work of a remarkable Soviet optician — inventor and designer D. D. Maksutov (1896-1964).[1] During this time at GOI (State Institute of Optics) he made the optics for Schmidt cameras of 40 and 30 cm in diameter; the 40-cm instrument was made in the workshop of the Kazan Observatory, for which it was designed. In the hands of the experienced observer this telescope now permits obtaining excellent photographs. Mechanics of the 30-cm Schmidt telescope made in the Astronomical Institute for the Tashkent Observatory, perished during the war. D. D. Maksutov made for the Erevan Observatory a 40-cm aplanatic reflector. N. G. Ponomarev and I. I. Grebenshchikov developed during this time the idea of light welded mirrors, which even now is considered extremely promising.

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[1]Maksutov, Dmitriy Dmitriyevich (1896-1964). Corresponding member of the Academy of Sciences USSR from 1946, has been awarded two orders of Lenin and the "Znak Pocheta," and twice the laureate of State prise (1941 and 1946).

In 1930 he organized the astronomical optics laboratory at the Institute of Optics in Leningrad. From 1952 to the end of his life he worked at the main astronomical observatory of the USSR at Pulkovo. He has the invention of a new optical catadioptric layour (meniscus), which has obtained wide application not only in astronomy, but also in other areas of science and technology.

At the State Optical Instrument Plant a special design group for astronomical instrument manufacture was formed, headed by N. G. Ponomarev. This group worked on the design of a large reflector, but it was interrupted by the war, during which N. G. Ponomarev died.

The first steps of domestic electrophotometry were taken in the prewar years. The first experiments of this kind were conducted in 1933 by V. B. Nikonov at Pulkovo. In 1938 V. B. Nikonov and P. G. Kulikovskiy constructed an electrophotometer with photocell and tested it on the Abastumani reflector. At approximately the same time N. N. Pavlov at Pulkovo began to record the transit of stars on a transit instrument having a photocell. At the Central Scientific Research Institute of Engineers in Geodesy and Cartography P. S. Popov constructed a quartz clock.

The attack of fascist Germany on our country inflicted great damage on Soviet astronomy. The Simeiz and Pulkovo Observatories were destroyed; the meter reflector and mounting of the 81-cm refractor and the just-completed horizontal solar telescope designed by N. G. Ponomarev, the building and tower were destroyed. However, the primary astrometric instruments of the Pulkovo Observatory and part of its library was nevertheless saved.

The war forced Soviet astronomy to mobilize its forces to aid the front. Many astronomers fought in the war; the work of observatories supplying the country with the exact time was stepped up.

During the war Maksutov invented a tool which strongly influenced the development of astroinstrument manufacture in our country, namely, simply manufactured (all optical surfaces spherical) meniscus systems which made possible the creation of many different astronomical instruments.

After the war began restoration of destroyed observatories, which it was decided to do in a volume considerably exceedingly the prewar.

Dmitriy Dmitriyevich
Maksutov

1896-1964

The Simeiz Observatory was separated from the Pulkovo Observatory and became an independent establishment — the Crimean Astrophysical Observatory of the Academy of Sciences of the USSR. It was, however, decided that its construction would be more expedient at a new site which was rapidly selected near Bakhchisaraya (see V. F. Gaze, 1948). In exchange for being destroyed the observatory obtained a 122-cm Zeiss reflector and a double 40-cm astrograph.

Pulkovo Observatory was rebuilt on its old site, but was considerably expanded. The first section of the observatory was solemnly opened in 1954. The old Pulkovo instruments — large transit instruments and normal astrograph — were augmented by a photographic zenith telescope, great meridian circle designed by L. A. Sukharev and made at the Kiev plant "Arsenal," and a new zenith telescope with an 18-cm objective. Furthermore, the observatory obtained a 65-cm

Zeiss refractor, a short-focus astrograph (SFA) and polar telescope in the A. A. Mikhaylov system — fixed telescope for observation of the celestial pole region. The solar telescope designed by N. G. Ponomarev was restored, and recently at Pulkovo one more was put in, manufactured serially at the GOMZ. At the observatory new areas began to develop, and the first was radio astronomy. The astroinstrument section was organized and directed by Maksutov until his death.

After the war several new observatories were organized. At Alma Ata the Astrophysical Institute headed by V. G. Fesenkov and the Astrobotany Sector under G. A. Tikhov began operation. Near Erevan, in Byurakan, construction began on the astrophysical observatory of the Academy of Sciences of the Armenian Soviet Socialist Republic. Twenty kilometers from Kislovodsk appeared the Mountain Astronomical Station of Pulkovo Observatory.

In Goloseyevo Wood, near Kiev (now within the boundaries of the city), was built the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian Soviet Socialist Republic (main Astronomical Observatory) initially for astrometric studies. And, finally, nearby Shemaka, 150 km from Baku, the observatory for the Academy of Sciences of the Azerbaydzhan Soviet Socialist Republic was constructed.

The observatory of Moscow University was expanded and transferred to the Lenin Mountains.

In the far east, in Ussuriysk, was organized solar station, and the Siberian branch of the Academy of Sciences of the USSR constructed a solar observatory nearby Irkutsk.

In the Urals the observatory for Sverdlovsk University (O. A., Mel'nikov, 1960) was constructed.

With the loss of the Simeiz reflector Soviet astronomers again remained without a large astrophysical telescope. Therefore

immediately after the war it was decided to order two large telescopes (diameter 170-200 and 120 cm) from the United States. However, because of the complexity of international relations the negotiations were interrupted. An attempt to order a 185-centimeter telescope in England was also a failure; it became clear that the country would have to rely only on its own forces. In 1954 it was decided that the home industry would prepare a telescope with a mirrow diameter of 260 cm. This work demanded new measures - after all, until then we had made mirrors with a diameter only a little more than a meter, and the difficulties of manufacture grow proportionally to the high degree of diameter of a telescope. Work was headed by design bureau under B. K. Ioannisiani, who had begun his own work under N. G. Ponomarev. Certain glass plants were built and a special grinding machine was developed; many specialized enterprises participated in the work. In 1961 this telescope, named for the deceased G. A. Shayn, was mounted at the Crimean Observatory.

By that time, the 1950's, the optical-mechanical industry had manufactured several instruments, which compensated for the instruments lost during the war. Under the leadership of B. K. Ionnisiani the GOI manufactured two nebular spectrographs for the Simeiz and Byurakan Observatories, several expeditionary slitless quartz ASI-5 spectrographs (Byurakran, Pulkovo, GAISh). At the GOMZ an already existing optical system 64 cm in diameter and with a focal ration of 1:1.5 was mounted fcr Simeiz Observatory. In that same period at the GOI two big meniscus telescopes were manufactured: a 50-centimeter for the Alma-Atin Observatory and a 70-centimeter with objective prism for Abastumani. Somewhat later at the GOMZ a 50-centimeter Maksutov AZT-5 camera was made for the GAISh. And, finally, one should note the recently made 70-centimeter astrometric astrograph for the Maksutov AZT-16 system, which now is in Chile at a station of the Pulkovo Observatory. The simplicity of manufacture of Maksutov systems resulted in their acknowledgement in other countries. At present in the United States, for example, many 20-30-centimeter telescopes have been built according to this scheme.

Meniscus telescope, Pulkovo Observatory.

In the 1950's GOMZ turned out 50-centimeter MTM-500 meniscus telescopes with a focal length 6.5 m and fixed focus, facilitating work with complex equipment. The optics of these instruments, set up in the Crimea and at Pulkovo, was calculated by D. D. Maksutov, the mechanics designed by P. V. Dobychin.

The sixty-four-centimeter chamber allowed G. A. Shayn and V. F. Gaze to carry out an extensive cycle of works on the study of emission nebulae.

Nebulae were photographed through a comparatively narrow filter in the light of the H_α hydrogen line; the background of the sky was suppressed; the method turned out to be very effective — with its help Crimean researchers discovered a multitude of new gaseous nubulea in the Milky Way and other galaxies.

At the Alma-Atin Observatory (made at the GOI) the very simple to control 50-centimeter Maksutov telescope (focal ration 1:2.5) also was used to study the structure of gas and gas-dust nebulae (V. G. Fesenkov and D. A. Rozhkovskiy).

The seventy-centimeter Maksutov telescope of the Abastumani Observatory with automatic control can work with an objective prism; with its help many stars radiating the H_α line have been found (M. V. Dolidze). Of the same kind of instruments it is impossible not to mention the Schmidt telescope, mounted at the Byurakan Observatory and having a correcting plate diameter of 100 cm.

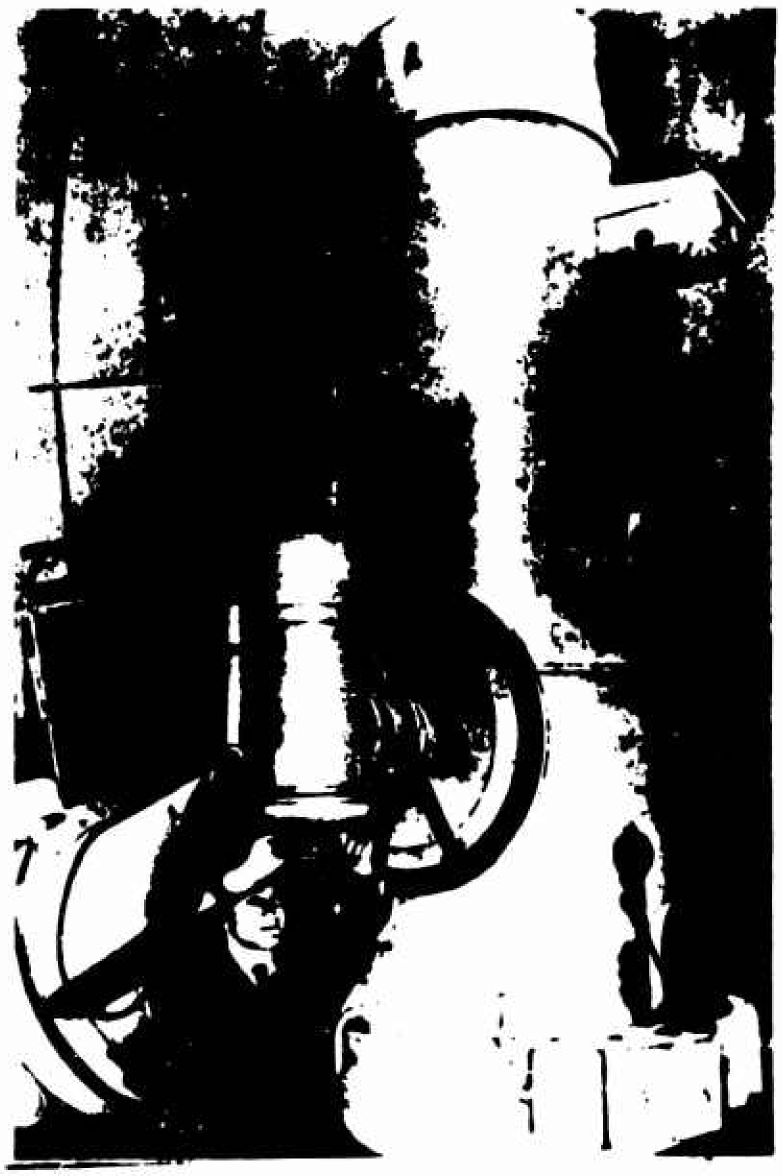
The postwar period saw the first Soviet investigations using fundamentally new instruments. In 1948 A. A. Kalinyak, V. I. Krasovskiy and V. B. Nikonov using an infrared ray-sensitive image converter photographed at the Simeiz Observatory the central condensation of our Galaxy, revealing its region, closed by absorbing matter. Soon V. I. Krasovskiy photographed on the same equipment the radiation spectrum of the earth's atmosphere to a wavelength of 11,000 Å. In the same year A. B. Severnyy and A. B. Gil'varg

calculated and prepared the first interference-polarization light filter in the USSR, making it possible to observe and to film the solar prominences and the chromosphere.

Although the basis of contemporary observation astronomy is the big reflectors, we, describing development of the equipment of our astronomy, cannot fail to mention instruments which seem small to us now. First, solar and astrometric instruments, which equip many of our observatories, and are not very large. Secondly, it is impossible to forget what an event, let us say, in the prewar period and in the first years after the war, it was when an observatory which had long since not had any new equipment received even a small telescope. A new instrument always leads to new programs of observations, allows solving problems inaccessible to old instruments; it requires new people for servicing and treatment of results — in one word, its appearance activates the whole life of an observatory.

In 1953 began construction of the tower solar telescope of Crimean Observatory (see the section "The Sun"). Instruments of the same type were obtained by GAISh and the Institute of Terrestrial Magnetism, Ionosphere and Propagation of Radio Waves of the Academy of Sciences, USSR (IZMIRAN). Zeiss extraeclipsing coronagraphs were mounted at the Mountain Astronical Station nearby Kislovodsk and at the Astrophysical Institute of the Academy of Sciences, Kazakh Soviet Socialist Republic; the same instrument of domestic production appeared in the Crimea.

Many instruments were timed for the beginning of the International Geophysical Year. These include twelve chromosphere-photosphere telescopes with interference-polarization filters, six zenith telescopes with 18-centimeter objectives, transit instruments, exact pendulum "Standard" clocks. Somewhat later appeared a series of modernized 70-centimeter AZT-8 telescopes, the first AZT-2 copies of which were at GAISh and the Main Astronomical Observatory of the Academy of Sciences USSR, and also a



Meniscus telescope at Abastumani; diameter of meniscus 70 cm.

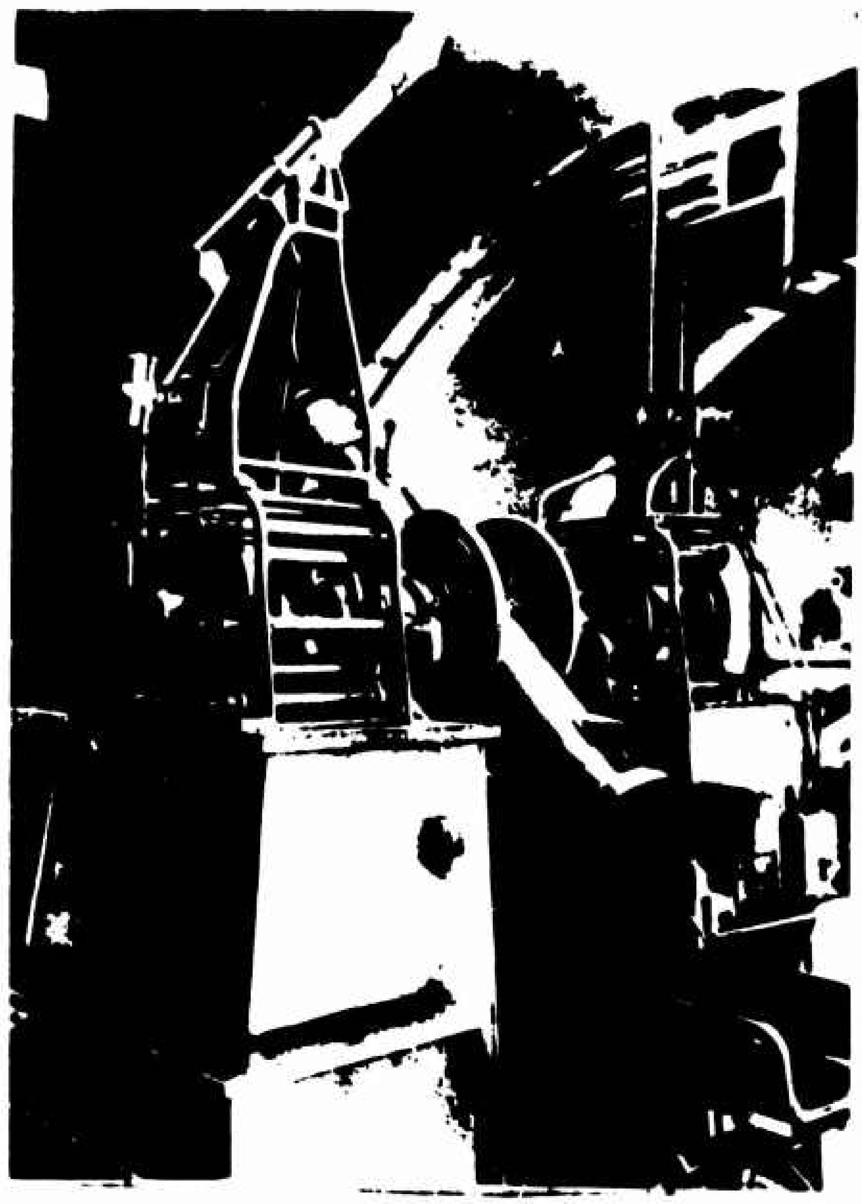
series of ATsU-5 solar horizontal telescopes with ASP-20 spectrographs (Pulkovo, Pirkuli, Goloseyevo, Abastumani, Tashkent, Sverdlovsk, Irkutsk, Ussuriysk, Alma Ata). The Leningrad plant made a large meridian circle for the new observatory of Moscow University in the Lenin Mountains.

Among recording and measuring instruments made in the USSR one should mention the fine printing chronographs of the Leningrad electric clock plant. At the astrometric laboratory of the Pulkovo Observatory L. A. Sukharev and V. D. Shkutov constructed an original semiautomatic instrument for photoelectrical measurements of photographs of a divided circle, which is being used successfully to treat materials of the Chile expedition. Work in this direction

Schmidt meter telescope (Byurakan Astrophysical Observatory).

is being conducted also in the Nikolayev branch of the Pulkovo Observatory and in the Main Astronomical Observatory of the Academy of Sciences, Ukrainian SSR. Here it is appropriate to mention that in many Soviet observatories (Pulkovo, Moscow – GAISh, Nikolayev and others) calculating laboratories computers have been organized, where a huge volume of calculations connected with the treatment of observations is being carried out.

Observatories of the time service obtained also imported quartz clocks, and some of them – faceless Danjaune [Translator's Note: Exact spelling of name not found. This spelling is one possible way to translate the Russian Данжон (Danzhon)].



GAISh meridian circle.

prismatic astrolabes which, as is assumed, must give a higher accuracy of determination of coordinates and time.

But it is time to finish this somewhat tiresome, although very informative to every astronomer, list of instruments and to try to grasp tendencies, set results and understand the prospects of our observation astronomy.

Let us consider briefly the role of new technology in astronomy. If, as already was said, telescopes are constructed only for the needs of astronomy and are almost nowhere used greater, then devices for registration and measurement of radiation collected by telescope are not specifically for astronomy and are usually taken from other

areas of technology. It is clear that they undergo certain changes, since they must satisfy requirements of astronomers. Thus it was with photography in its time. Photoemulsions, developed initially for other purposes were used for photographing comparatively bright astronomical objects, and then, when their sensitivity for great exposures was increased also for weaker objects.

We may rightfully say that new technology of photography with its high sensitivity to ultraviolet light, with its colossal information ability (even a small photograph can register millions of units of information) and ability to hold the action of light opened before astronomers a new world, inaccessible with former methods of investigation.

The use of photoeffect in astronomy, especially after the invention of the photomultiplier by L. A. Kubetskiy (1906-1959), also resulted in obtaining new data about celestial objects. Use of photomultipliers made stellar photometry much more exact, and permitted revealing the polarization of light of certain stars.

At present in astronomy image amplifiers and infrared radiation receivers have begun to be used; they are taken from "nonastronomical" regions of technology and need changes in accordance with the requirements of astronomy. These instruments of new technology permit conducting observations in regions of the spectrum inaccessible earlier.

Do automatic devices on telescopes and cybernetic instruments belong to this category? Regarding the last ones, we stand now, apparently, on the threshold of their astronomical use. Besides electronic computers, widely used at present for astronomical calculations (for example, during calculation of models of the internal structure of stars and during the composition of astronomical yearbooks), the creation of many laboratory instruments facilitating and accelerating treatment of astronomical information is possible. Actually, photograph obtained through half an hour on a Schmidt

telescope contains several millions of units of information. Abroad, in particular in the German Democratic Republic, automatic devices measuring the coordinates and brightness of stars and even determining their proper motions already have been created (by comparison of two photographs of a defined area of the sky, obtained on the same telescope with an interval of several decades). Many observatories adopted comparatively simple instruments facilitating the treatment of astronomical negatives — devices to intensity, isophotmeters, etc. If they are sufficiently reliable and exact, the saving of time which they give is very perceptible.

Automating telescopes was somewhat different. Here electromechanical devices developed for other purposes are used in modified form. These devices guide the telescope to a chosen star, hold it on the spectrograph slit, move the dome in accordance with the shift of the telescope, determine exposure, etc. In unfailing work these devices give certain additional time for observations. But their presence is not fundamentally important for the execution of many works. Thus, the 2.5-meter telescope of the American Mount Wilson Observatory entered service in 1917. On it one of the fundamental discoveries in astronomy of the XXth Century was made — the red shift in the spectra of distant galaxies. Meanwhile, at that time the telescope was put into motion by weight clockwork and had practically no automatic devices. This discovery was made possible by the creation of a large telescope with good optical qualities, a spectrograph perfect for those times and sensitive photomaterials. The 125-cm diameter telescope of the Haute Provence Observatory (France) gives good results, although as yet it has only one electrical device (clockwork) and is excellently guided and aimed manually. Therefore the appearance here of small (20-30 cm), fully automated instruments in some measure alerted the astronomer-observer; possibilities are frequently limited by the small quantity of light, the spectrograph slit or diaphragm of the photometer, but not by the fact that the tower dome is rotated with the help of two pushbuttons.

Furthermore, as practice shows, experimental examples of similar automatic devices are not very reliable and time is wasted in eliminating their malfunctions. The completion of all such devices raises the price of a telescope. In connection with this it seems expedient to concentrate attention on key problems — the creation of bigger high-quality mirrors, improved spectrographs, photoemulsions and other radiation and image receivers. The telescope can be automated after it is determined how far this is necessary. It is clear that this does not mean that automatic devices for telescopes should not be developed. On large instruments it is necessary to select the best variant of all systems, preliminarily thoroughly testing it in working conditions. As example of a telescope useful for solving this problem is the RM-700 reflector at Pulkovo Observatory. Clearly the above considerations carry a somewhat subjective character; the opinion of telescope manufacturers frequently is different — they sometimes consider creating conveniences during observations by an innovation of fundamental character, which makes it possible to obtain new scientific results.

In 1950's work expanded on the creation of new astronomical technology in the USSR. Here we must mention the use of television systems, started at Pulkovo for astronomical observations (N. F. Kuprevich). Somewhat later analogous works were started in the Crimea and already led to very reassuring results.

GAISh began the development of infrared technology, founded on the use of different photoresistances (V. I. Moroz). The basic subject here is spectroscopy of the planets.

Many observatories started to use image converters. GAISh jointly with the electric vacuum industry developed contact converters for astrospectroscopy (V. I. Volkov, V. F. Yesipov, P. V. Shcheglov).

Obtaining imported photomultipliers, the Crimean Observatory rapidly adjusted itself to contemporary electrophotometry. It is

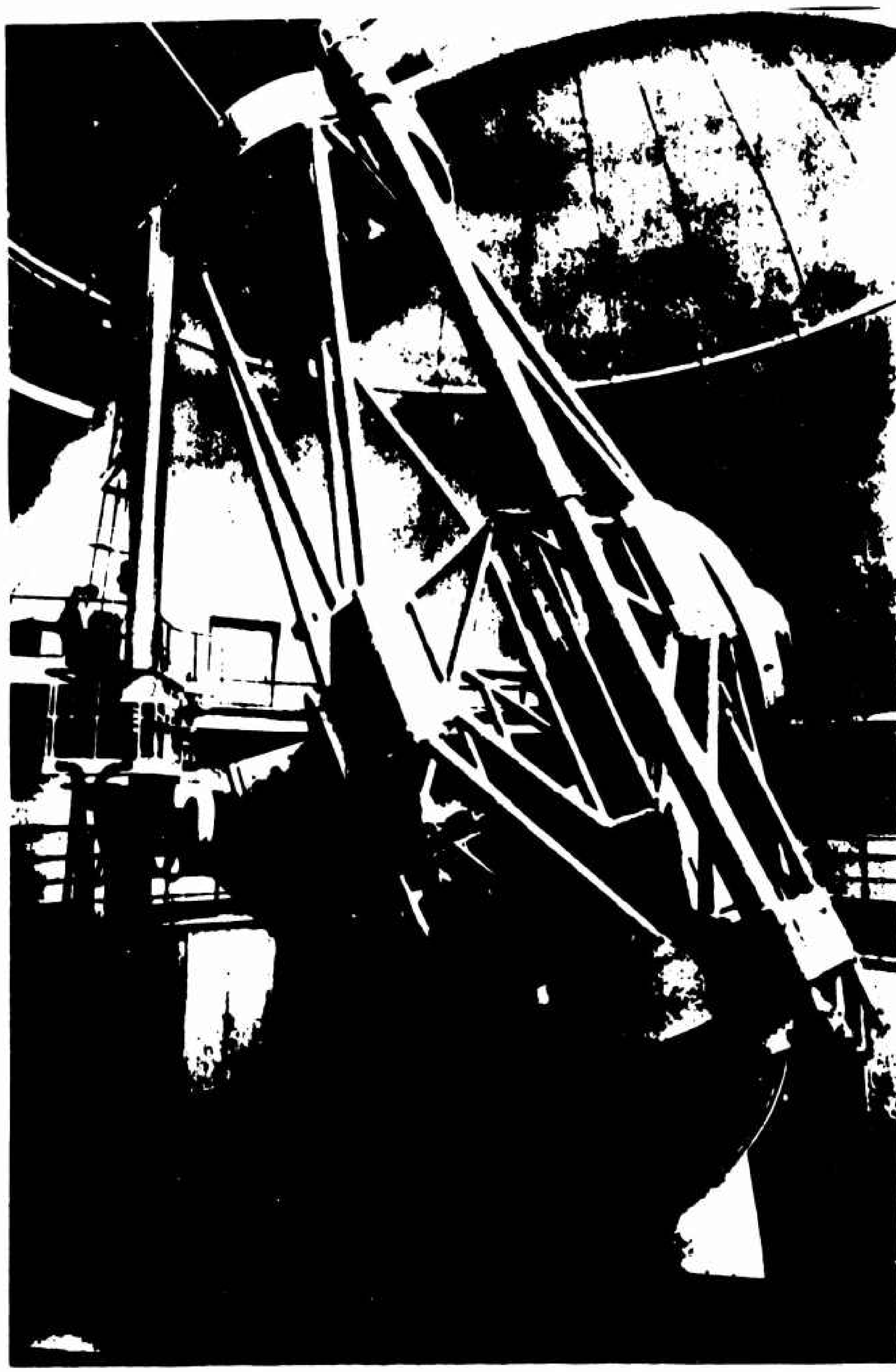
necessary to note that in recent years our industry began to manufacture photomultipliers which are completely useful for astronomical measurements.

P. V. Meyklyar in the Kazan branch of NIKFI developed in 1960 a series of astronomical photoemulsions. The problem here is for the astronomical photoemulsion not to strongly decrease in sensitivity in the change to long exposures (as is peculiar to the usual photomaterials).

It is necessary to note GOI's mastery of the production of contemporary diffraction gratings with light concentration in the h[illegible] interval of wavelengths (F. M. Gerasimov). Somewhat later the production of copies from these grids was organized, much cheaper as compared to the originals and replacing them in installations of moderate dispersion. With their help many observatories constructed good spectrographs, which will be mentioned below.

The biggest of the present domestic production telescopes are the 125-centimeter GAISh reflector, which began work in 1960, and the 260-centimeter ZTSh reflector of the Crimean Observatory. They are mounted near one another in the Naychnyy settlement into which the growing Crimean Observatory has been transformed. At present already certain operation experience with these instruments has been accumulated. Both telescopes are used basically for spectroscopy. The diameter of the image of a star on good photographs, obtained with the GAISh reflector is 2", and the 2.6 meter telescope sometimes gives an image in 1". For the GAISh telescope the workshop made a spectrograph with a concentric Popov camera, which makes it possible to obtain in 4 hours the spectrum of a $13^{m}.5$ star with a dispersion of 120 Å/mm. Made at the GOMZ plant, the spectrograph of the 2.6-meter telescope permits photographing spectra of 8-12^{m} stars with dispersion 180 Å/mm (T. S. Belyakin and others, 1963). The spectrograph for ZTSh with dispersion 450 Å/mm and concentric mirror-lens camera with a focal ratio of 1:0.45, built in the observatory workshop, permitted obtaining the spectrum of the galaxy $1?^{m}.2$ in 6 hours. In 1965 the concentric mirror-lens camera on the

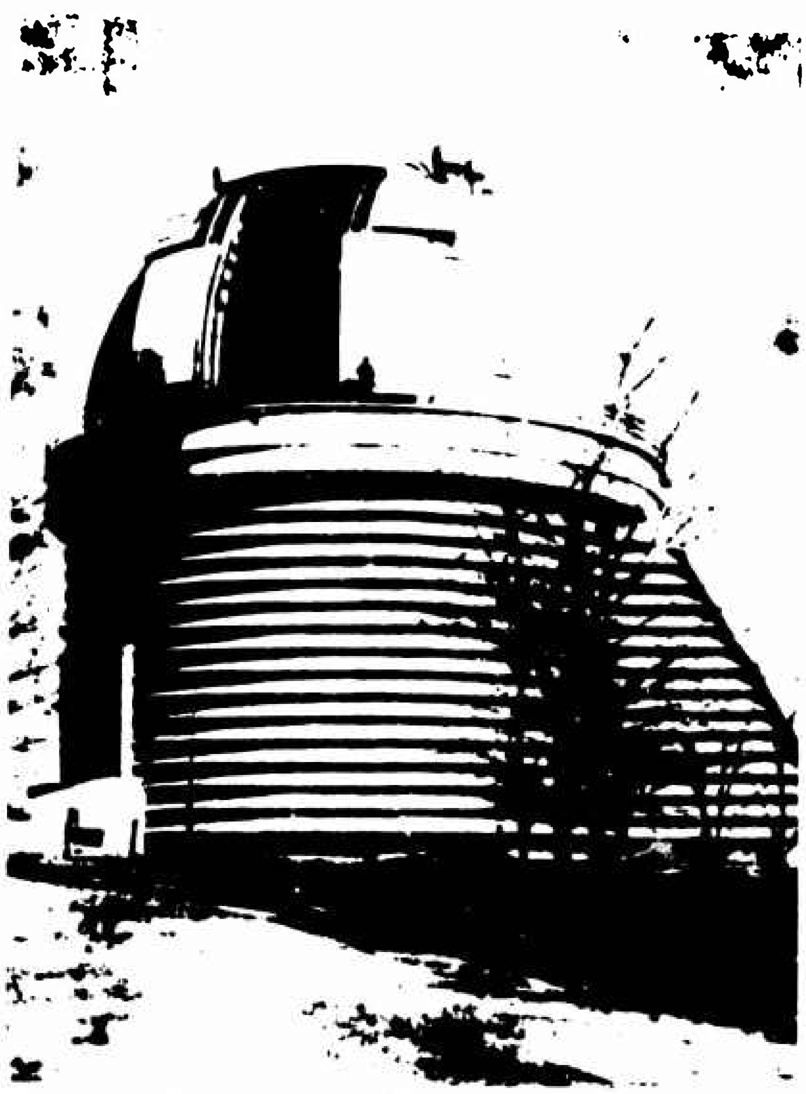
GAISh reflector (Crimean station) with mirror diameter of 125 cm.



Large reflector (diameter of mirror 2.6 m) named after G. A. Shayn (Crimean Astrophysical Observatory).

GAISh spectrograph was replaced by a lens objective with a focal ratio 1:0.85, which constructs the spectrum on a contact image converter, thus making the photographed image considerably brighter. Dispersion turned out to be 240 Å/mm, and the maximum stellar magnitude attained $16^{m}.5$ at an exposure of 2 hours and slit width of 3". The limit in this case is placed by the background of the sky; by making the slot three times smaller, it would have been possible to reach in 6 hours of exposure $17^{m}.5$ objects. However, the unpredictable atmosphere and the not very good quality of the telescope do not permit this (E. A. Dibay and others, 1966).

The same spectrograph, mounted on a telescope 2.6 m in diameter, permitted obtaining a well exposed spectrum of a $17^{m}.5$ object in 2 hours at night with clear images, i.e., it allows working with a



Tower of large reflector.

dispersion twice as large and three times faster than the spectrograph with registration on a photographic plate. Although the working field of a contact converter is less, and the resolution worse than for the usual camera, it can be used to make a spectrograph of objects considerably weaker than in the case of the usual photographing, to reduce essentially the time expended on the observation program.

At present on observatories much auxiliary equipment is prepared using the above ready elements. This includes spectrographs, spectrometers, polarimeters, interferometers, microphotometers, electrophotometers. Many of these constructions are carried out rationally, without superfluous complications and have proven themselves well. Unfortunately, similar comparatively cheap and effective instruments are not serially produced by industry.

If one were to talk about the prospects of our astronomical instrument industry then the practice of manufacturing instruments serially is fully justified, since telescopes become chaper. Extraordinarily timely would be the manufacture of a series of simple reflectors 1-1.5 m in diameter. It is clear that the design of such equipment must consider the experience of observatories working with pilot instruments of a series. One of the nearest problems is making the astronomical constructions lighter. For this reason in astronomical instrument making, where basic expenditures go to labor, and not to materials, it is possible to allow the use of materials used in new technology (titanium, quartz, new polymers), since the extraordinarily increasing weight of large telescopes not only is not necessary but in many cases is harmful.

For the development of astronomy selection of the place for mounting the great telescopes is extremely important. For the last decade the USSR conducted extensive work in this area, and now defined conclusion can be made. For example, it became clear that it is very difficult to select a place for a large telescope using

a little instrument. Image quality is affected by both big and small heterogeneities of the atmosphere; a small telescope records first displacement, secondly image smearing; to see the totality of these phenomena is difficult. In order to analyze the influence of all atmospheric heterogeneities, it is necessary to simulate a big instrument at least with the help of a periscopic cap with the same sensitivity to image distortions as the large telescope. For sure judgement about the quality of a given place from the astronomical point of view yearly series of observations are needed, clipping off several months can lead to gross errors. An important role is played by the condition of the local microclimate; one should as far as possible select a place with small diurnal temperature drop near the instrument. At Simeize with his almost complete isothermy G. A. Shayn using a meter reflector observed in his time stellar images $0''.7$ in diameter. It is also clear that a large instrument, as was already said, should be in a place with a great number of clear nights, since its huge cost should recompensed in the most effective way. It is necessary to turn serious attention to the installation of large telescopes in Central Asia with incomparable more favorable climatic conditions for observations.

Recently a 2-meter reflector was put into operation at the Shemaka Observatory; a 2.6-meter telescope is under construction for the Byurakan Observatory for which the prototype is the Crimean reflector, and the 6-meter reflector in the Northern Caucasus. These telescopes undoubtedly will considerably accelerate the achievement by our country of world level in large astronomical instruments — a problem which still stands before Soviet astronomy.

Finishing this historical survey, we want to turn attention to one more important factor — the appearance in our country of a considerable number of astronomers who realize the necessity of the big telescopes, participate in it and who already have although not very great, but useful experience in this difficult matter. It is necessary to think that the scientific and technical progress of

our country, attention to the development of Soviet astronomy by the Party and the Government, in combination with the great work of many people, which has already begun, will put our astronomy in a befitting place in instrument equipment.

ASTROMETRY

Astrometry is the oldest and at the same time current branch of astronomy. Astrometrical work is the determination of coordinates of celestial bodies, the angular distances between them, the measurement of time, and also related to astrometry the exact determinations of geographic coordinates lay the foundation for different investigations in celestial mechanics, stellar astronomy, geophysics and geodesy. Astrometry is characterized by close contact with practice. It developed to solve the problems of cartography, navigation and calculation of time. And now its development frequently is stimulated by practical requirements. For example, the discovery of irregularity in the rotation of the earth gave the impulse for perfecting methods of measuring time and improving star catalogs, containing the right ascensions of stars. New methods and tools for the most precise determination of latitude and declinations of stars appeared in connection with progress in the study of the motion of terrestrial poles.

Among distinguished divisions of astrometry in the last decade fundamental astrometry, photographic astrometry, time service and latitude service developed strongly. The main problem of fundamental astrometry is the construction of a basic inertial system of celestial coordinates, for which fundamental star catalogs are composed containing the most precise positions and proper motions of the chosen fundamental stars, derived on the basis of the yearly observations of different observatories on the earth. Fundamental

astrometry involves the teaching of methods and tools for determination of coordinates of the heavenly bodies from observations, and also questions of determination of the basic astronomical constants. In photographic astrometry methods of using photography to determine positions and for the investigation of motions of celestial bodies and for other measurements in the sky are examined. The basic problem of the time service and latitude service is study of the rotation of the earth, in particular irregularity of the velocity of its rotation, motion of terrestrial poles and changes of geographic coordinates; consequently, these two divisions of astrometry are closely connected with geodesy and geophysics. Furthermore, time service studies the calculation of time by means of astronomical observations and by methods of physics (using molecular and atomic standards of frequency). Work in astrometry is not limited to these main divisions. It also includes micrometric, very exact measurements of small angular distances in the sky, including observations of binary stars, study of the figure of the moon and its rotation, in particular libration of the moon, and also certain other measuring problems.

Contemporary requirements for the accuracy of astrometric data are so high that as a rule they can be satisfied through the efforts of separate observatories, inasmuch as results of observations are distorted by systematic errors (instruments, personal or refractional), the most complete investigation of which is possible only by a comparison of materials of observations from different observatories; besides this, the great number of objects being observed and their distribution in the sky frequently make impossible fulfillment of the work at one observatory. Therefore even in the last century much astrometric work was conducted by the joint efforts of scientists in many countries. An example is the German Astronomical Society organized in the 1860's ("Astronomische Gesellschaft" - AG) in which the determination of exact positions of all stars in the sky up to the ninth magnitude and composition of zone catalogs AGK-1 involved around 20 observatories of various countries, including Russian observatories in Kazan, Nikolayev and Derpt. The tendency to unification of forces and means of different observatories is especially characteristic for contemporary astrometry.

In the development of astrometric work of prerevolutionary Russia an exceptional role belonged to Pulkovo Observatory, founded in 1839 under the leadership and direct participation of the outstanding astronomer of the first half of the nineteenth century V. Ya. Struve. Thanks to his energy and care the observatory was equipped with first-class instruments and entered service immediately as a large-scale establishment, rapidly winning international authority. In his famous description of the Pulkovo Observatory[1] V. Ya. Struve expounded the long-term plan of its scientific activity, which even now retains its value. According to Struve's plan one of the main problems of an observatory is systematic determinations of the coordinates of all bright stars in the sky by absolute methods using a large transit instrument and a vertical circle. The series of Pulkovo catalogs composed by this plan for 1845, 1865, 1885, 1905 and 1930, to which now must be added the recently completed 1955 catalogs, is a remarkable example of an expediently planned and well carried out perennial scientific enterprise. At Pulkovo many other stellar catalogs were composed also, basic astronomical constants were determined, extensive work was conducted on photographic observations of the heavenly bodies, started by the founder of the Russian school of astrophotography by S. K. Kostinskiy (1867-1936). Other astronomical observatories of prerevolutionary Russia also carried out a great deal of valuable investigations, but their work was less regular mainly due to the low number of personnel and the deficiencies of their means. The development of their work in the Soviet Union can be divided into three periods, distinguished according to the character of the conducted investigations, their intensity and span.

In the first, "preparatory" period, lasting around 15 years, the work of Soviet astronomical establishments although revived, still was little changed as compared to the prerevolutionary period. The observatories carried out different, only slightly connected

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[1]Description de l'Observatoire Astronomique Central de Pulkova. St. - Pét., 1845. (Description of the Main Astronomical Observatory at Pulkovo).

investigations; there still were no common directions and plans. Only in the youngest branch of astrometry — time service appearing at the beginning of the 1920's were measures conducted which were directed towards unification of the work of observatories; we will deal with this later.

A critical moment and the beginning of the second period of development of Soviet astrometry was the first astrometrical conference, convoked at the Pulkovo Observatory in May, 1932, at which was begun the large collective work, which soon united the astrometric forces of Soviet observatories. At this conference questions of the coordination of time services activity were discussed; the problem of organization of Soviet latitude service and the creation of a Far Eastern latitudinal station; were brought up; a decision on collective meridian observations of "geodesic stars" was made, i.e., stars utilized in widely developing geodesic work in the USSR; finally, this conference discussed for the first time the idea of an extensive measure undertaken for the creation of a Catalog of Faint Stars (KSZ) and the use of observations of small planets to orient in the sky the system of coordinates of the star catalog. In the 1930's in connection with decisions of the conference a general rise of astrometric work in our country began.

The following important stage for Soviet astrometry was a conference in 1938, at which the plan for the Catalog of Faint Stars (KSZ) was accepted. In this plan one of the most important elements was photographic observations of galaxies very remote and practically stationary in the sky for the purpose of determining the stellar motions independently of the sun's motion and the rotation of our galaxy. Various works connected with the KSZ included the majority of observatories of the USSR, leading the work in astrometry.

Loosed by German fascism, the second world war brought to the peoples of the Soviet Union and other countries innumerable disasters. Many scientific establishments suffered. The Pulkovo and Simeiz Observatories were destroyed. Soviet observatories remaining on unoccupied territory were rebuilt during the war years through their own efforts in order to render all possible help to the country and

the front. Many talented astronomers died (the head of the Kharkov time service Yu. N. Fadeyev, and the Nikolayev — M. N. Stoilov, astrometerist V. G. Shaposhnikov and others; during the blockade of Leningrad F. F. Rents, V. A. Yelistratov and N. V. Tsimmerman died). The war interrupted the successfully begun work on the Catalog of Faint Stars and delayed the development of Soviet astrometry by almost ten years.

Completing post-war reconstruction, i.e., approximately 1950, Soviet astrometry entered the third period of its development, characterized by a broad development of work in all basic directions, growth of instruments and technical equipment of observatories and the expansion of international communications. Work on the KSZ was renewed at Soviet observatories soon after the termination of the war, and in the 1950's was joined by many foreign observatories. The activity of the Soviet time service, which now is headed by the Committee of Standards attached to the Council of Ministers of the USSR, was placed on a broad footing.

At the beginning of the 1950's the Soviet latitude service was organized, headed by the Poltava Observatory of the Academy of Sciences of the Ukrainian SSR. Regular calculations of solar coordinates according to latitudinal observations of observatories of the USSR were begun. Work in the time and latitude service was especially stepped up in 1957 in connection with the International Geophysical Year, when equipment of observatories was considerably increased and the programs of observations expanded. From October, 1957, after the launching in the USSR of the first artificial earth satellite in the world, a direction of astrometric work began to develop — determination of coordinates and investigation of the movement of spacecraft rapidly moving across the sky. The basic works in astrometry are now being conducted collectively with the participation of many observatories, Soviet and foreign. With respect to their own group of problems these works occupy advanced positions on the front of world science.

After these general remarks we will examine briefly the specific achievements of Soviet astrometry in its basic divisions.

The work in fundamental astrometry now is conducted at nine observatories in the Soviet Union having meridian instruments. At Pulkovo continue regular absolute determinations of coordinates of the fundamental stars by strict Pulkovo methods with the large transit instrument and vertical circle of V. Ya. Struve. These works are the most important in astrometry, inasmuch as absolute star catalogs are composed in the original system and provide the basis for the basic star catalogs, fixing in the sky the basic system of coordinates. During the time of Soviet power at Pulkovo several absolute catalogs were completed, including the two above catalogs from the plan of V. Ya. Struve; of them the last — 1955 Catalog — besides 550 bright stars of Struve contains yet as many fundamental faint stars from the KSZ. It is necessary to note an important investigation of the Pulkovo astronomer A. A. Nemiro, who analyzed and processed 100 years of Pulkovo absolute determinations of right ascensions with the large transit instrument took for every star not only the exact position, but also proper motion and composed the first fundamental catalog in the world obtained from observations with one instrument. The new catalog permitted revealing essential errors in contemporary basic systems, including those in the conventional international catalog FK3. Absolute determinations of the coordinates of heavenly bodies have been conducted for many years at Nikolayev (branch of the Pulkovo Observatory), at Kazan (V. P. Engelhardt Astronomical Observatory), and in post-war years also at Goloseyev (Main Astronomical Observatory at the Academy of Sciences of the Ukrainian Soviet Socialist Republic) and at Tashkent.

Among other star catalogs obtained in the USSR one should mention first the above catalog of geodesic stars. These stars were intensively observed in the middle 1930's at five Soviet observatories (Pulkovo, Moscow, Kazan, Nikolayev, and Tashkent) under the leadership of the Pulkovo astronomer N. V. Tsimmerman. The corresponding combined catalog, composed from these observations with the addition of bright fundamental stars observed at the observatories of various countries, was completed at Pulkovo before the war, but published only in 1948. This very exact catalog, containing 2957 stars of the northern sky, is still heavily used in Soviet geodesic works and

time services, and also at the Institute of Theoretical Astronomy of the Academy of Sciences of the USSR in composing the "USSR Astronomical Almanac."

Above the broad work on the Catalog of Faint Stars has already been mentioned. The plan of collective work on this great problem includes both meridian observations of around 1000 fundamental faint stars (FKSZ) and several tens of thousands of stars of the large KSZ, and photographic observations of chosen small planets and remote galaxies. Working lists of stars of the KSZ and FKSZ were composed in Moscow at the P. K. Sternberg State Astronomical Institute under the guidance of M. S. Zverev, at the Institute of Theoretical Astronomy N. S. Yakhontov developed a plan of observations for 10 chosen small planets, and the final lists of the celestial sites with galaxies were composed under the leadership of A. N. Deych at Pulkovo (for the northern sky), at Tashkent (in zones to -25°) and at Santiago, Chile (for the more southern zones). In meridian observations connected with the KSZ, besides the above six Soviet observatories university observatories at Kiev, Odessa and Kharkov participated, and in photographic observations — observatories at Pulkovo, Moscow (GAISh), Goloseyev, Tashkent and (from 1960) Nikolayev.

In 1952 at the Congress of the International Astronomical Union (IAU) at Rome a symposium took place on "The Astrometry of Faint Stars" in which the problem of creation of a KSZ was put to the international astronomical community. The congress made a resolution approving the creation of a KSZ; from this time work on the KSZ was joined by many foreign observatories, among which the most active turned out to be the observatories in Bucharest and Capetown; photographic observations connected with the KSZ were also joined by observatories in Shanghai (Zo-Se), Bordeaux, Toulouse, Santiago (Chile) and Sidney. From the 1950's many observatories have carried out meridian observations of the fundamental stars of the FKSZ, on the basis of which at Pulkovo M. S. Zverev and D. D. Polozhentsev composed the Preliminary Compiled Catalog (PFKSZ), published in 1958. At the congress of the IAU in Dublin in 1955 the problem of the KSZ with respect to meridian observations was combined with the

Nikolay Vladimirovich
Tsimmerman

1890-1942

problem of composing an international catalog of reference faint stars for new photographic re-observation of the many thousands of stars of zone catalogs for the northern sky. During the subsequent six years at 11 observatories of various countries, including the Pulkovo and Nikolayev, meridian observations were made of these stars, and consequently also all stars of the KSZ for the northern sky. The corresponding compiled catalog at present is being composed at the Naval Observatory in Washington. In those same years the observatories at Moscow, Kazan, Kiev, Odessa, Tashkent and Bucharest carried out extensive work on meridian observations of all stars of the KSZ from the north pole to declination -20°.

Regarding photographic observations according to the plan for the KSZ, then by 1964 at the many observatories of various countries over 5000 photographs of small planet and a large number of photographs of areas with galaxies had been obtained. For the northern hemisphere

photographing the galaxies for the first epochs[1] is basically completed; the Pulkovo and Tashkent observatories, who started these observations even before the war, have proceeded to experimental photographs of the second epochs; consequently, these observatories already can study stellar motion with respect to galaxies, which is the arm of these observations and can lead to interesting discoveries.

The Catalog of Faint Stars should embrace the whole sky — from north pole to south. Therefore in the middle 1950's, when work on observation on the northern hemisphere of the sky was set up, the organization of corresponding observations of the southern sky became pressing. During the last 20 years regular astrometric observations have been conducted on the southern hemisphere only at Capetown, and in principle and practice are insufficient for the KSZ, inasmuch as the reduction of complex systematic instrument and refractional errors requires the materials of parallel observations from several observatories (not less than three). Considering this circumstance, the Academy of Sciences of the USSR in 1958 resolved to organize an astronomical expedition to one of the observatories of the sourthern hemisphere. The report about this expedition at the astrometric conference in Cincinnati (USA, 1959) served to implement the organization of an international measure taken for meridian observation of reference faint stars of the southern sky (including all stars in the KSZ), in which up to now nearly 10 observatories have agreed to participate.

At the end of 1962 an expedition from the Pulkovo Observatory left for Chile, where at the new observatory of the University of Chile on Cerro Calan near Santiago work in the closest collaboration with Chilean astronomers successfully developed.

The plan of the expedition included absolute determinations of the coordinates of bright and faint fundamental stars by Pulkovo

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[1]The proper motions of stars are determined by comparing photographs taken at two moments (epochs) separated by a great interval of time (several decades).

methods with new original instruments (including the photographic vertical circle, proposed by the author of this article and made in the workshop of the Pulkovo Observatory), relative meridian observations on a large program of reference faint stars (and also all bright stars of the southern sky) using the meridian circle in Chile and photographing locations with galaxies on the two-meniscus astrograph of D. D. Maksutov, made by the Leningrad Optico-Mechanical Combine. The successful beginning of the work of the Soviet expedition in Chile under excellent climatic conditions provided the basis for an agreement between the Academy of Sciences of the USSR and the University of Chile for prolonged scientific collaboration in astronomy.

Thanks to the hard work of the Chilean expedition and the active participation of many Soviet and foreign observatories in observations to structure the KSZ, this problem now has a real promise of successful completion. Certainly, tying in the coordinate system of the KSZ to remote galaxies will be completely realized only after several decades – after obtaining photographs of galaxies in the second epochs.

Horizontal meridian circle of L. A. Sukharev (On the right L. A. Sukharev).

Speaking of the work of observatories in the USSR on fundamental astrometry, one should add that in 1958 at the Xth Congress of the International Astronomical Union in Moscow on the proposal of Soviet astronomers for observatories of various countries new pressing programs of meridian observations were recommended, including "Bright stars" and "Latitude stars." The first program provides for a new determination of the coordinates of all stars in the sky to $6^{m}.0$, including the "geodesic stars" observed by observatories in the USSR in the 1930's. Thus, the important problem about reobservation of the Catalog of Geodesic Stars is how organized as international work.

The "Latitudinal stars" program, composed at the GAISh, includes stars according to whose observations observatories of various countries study the movement of the pole. It is to be used for obtaining a rigid coordinate basis for putting into one system the results of all latitudinal observations and to study the age-old movement of the pole. Meridian observations of stars in the latitudinal programs of individual observatories were also conducted in past years [observatories at Odessa, Kazan, Uccle (Belgium) and others]. Now this work is on an international scale, thanks to which after several years of study on narrow effects in the movement of the pole it will be possible to rely on a reliable base in the form of a working catalog of exact positions and proper motions of latitudinal stars.

During the last few years an essential contribution in fundamental astronomy appeared in the time service, which determines the right ascension of stars from their own numerous observations with transit instruments. Much work in this area is conducted at Pulkovo, where under N. N. Pavlov, from very exact photoelectrical observations several star catalogs have been composed. The huge amount of material (150,000 observations) obtained by the USSR time services in 1957-1959 in connection with the International Geophysical Year, at present is being treated at Pulkovo to be used in a working catalog of the most exact right ascensions of around 500 stars. It is necessary to mention also on leading in Soviet observatories observations Danjaune [Translator's Note: exact spelling not found.

This spelling is one possibility for the Russian word Данжон] prismatic astrolabes, which, as it is known, permit correcting the system of coordinates of the fundamental catalog.

Work on the large fundamental star catalogs in past years was conducted mainly in Germany and the United States, although the most exact material for this purpose came from observations at the Pulkovo Observatory. The above work of Soviet observatories, especially absolute determinations of coordinates of stars and a whole complex of work on the Catalog of Faint Stars, including results of the expedition to Chile on the southern hemisphere, along with observations of observatories of other countries will compose extensive material for a new larger fundamental catalog of bright and faint stars in the original system of coordinates. This work is included in a long-term plan of the Pulkovo and other Soviet observatories, as one of the most important problems of Soviet astrometry for the next several years.

In astrometry the thorough investigations of instrument error, on which in many respects depends the accuracy and reliability of results, have played a huge role. Especially important is comprehensive investigation of instruments during absolute determinations of coordinates. In Soviet observatories extensive work is being conducted on the study of pivots, divided circles, micrometers, levels, and also the flexure of meridian instruments. Different methods are used, including the original (method of V. P. Linnik for the investigation of flexure, methods V. V. Podobed for determination of the irregularity of pivots, for detailed investigation of circles and others). Much attention is allotted to the development of new meridian instruments and auxiliary instruments (see the section "Tools and Instruments"). Of the original instruments, besides the above photographic vertical circle of the Chile expedition, the horizontal meridian circle (HMC) in which around the axis resolves a flat mirror, and observations are conducted through fixed horizontal telescopes located in the meridian to the north and south of the mirror. At Pulkovo the installation of a large HMC, was designed by L. A. Sukharev and built by the Kiev "Arsenal" plant.

Sergey Konstantinovich
Kostinskiy

1867-1936

We will examine now the basic works of observatories of the USSR on photographic astrometry. Even before the revolution they were being conducted at the Pulkovo, Moscow and Tashkent observatories; in 1952 they began at Goloseyev, and at 1960 also in Nikolayev, where now the "zone" astrograph, is set up, which before the war was at Pulkovo. One of the main problems of all these observatories during the last 25 years was photographic observations of a chosen minor planet and locations with galaxies according to the plan of the KSZ which was mentioned above. Just at the Pulkovo Observatory for this purpose over 1000 photographs of the minor planets and 900 photographs with galaxies were obtained. Observations of galaxies and minor planets at Pulkovo are conducted both with the large astrograph of old observatory at Krasnaya Presnaya and with the new wide-angle AFR-1, made at the Leningrad Optico-Mechanical Combine. It is necessary to note that at this plant also a number of high-precision KIM-3 instruments have been built for the measurement of astrophotographs up to 30 × 30 cm; these instruments are successfully

used in many observatories of the USSR. In Soviet observatories enormous work is being carried out on measurements of photographs of the minor planets and on treatment of measurements using electronic computers. At Pulkovo during the last few years not only their "own" photographs were measured, but also nearly 600 photographs of the minor planets sent by an understanding from the observatory in Capetown.

At Moscow and especially at the Pulkovo observatories glass archives of the old prerevolutionary photographs of different sections of the sky, which were obtained in Moscow by the astronomer-revolutionary P. K. Shternberg (1865-1920) and at Pulkovo by the pioneer of Russian astrophotography S. K. Kostinsky,(1867-1936) are being successfully used. Comparison of new photographs made with these instruments over 50-60 years with old photographs, permits extremely accurate determination of the proper motions of stars, star clusters, planetary nebulae and others. Investigations of the movement of different members of the Galaxy, even the most remote ones, give important material in the study of structure and dynamics of our stellar system. Among them we remember the work of A. N. Deych, who studied the proper motions of 18,000 faint stars in chosen areas of the northern sky, and the extensive treatise of P. P. Parenago, who investigated the movement and other characteristics of stars in region of the Orion nebula. Let us mention the recently completed work at Pulkovo of V. V. Lavdovskiy, who studied kinematic characteristics of 13 star clusters of our galaxy, and the well-known study of A. N. Deych, who measured a large number of photographs of the binary star 61 Cygnus and confirmed the presence near one of the stars of this pair of an invisible satellite with a mass, equal to 1/100 the mass of the sun. The last work has a cosmogonic value, inasmuch as it proves the existence near stars of planet-like satellites of small mass.

The large astrograph of the Moscow Observatory (GAISh) for many years has been used to photograph star variables to study their proper motions, and the Pulkovo zone astrograph even in the 1930's was used to photograph the circumpolar region of the sky and after

thorough measurement of the photographs a catalog was composed of the exact coordinates of over 11,000 faint stars with declination from +70° to the pole.

During the war the famous 30-inch refractor at Pulkovo was destroyed, with only the objective surviving. Instead of it, now at the observatory is a new 26-inch refractor (focal length 10.5 m), with which systematic work on determination of star parallaxes has been begun. This instrument is used also for photographic observations of binary stars, in which an automatic cassette is adapted, making it possible to obtain up to 50-60 images on one plate, from which then it is possible to select the best for subsequent treatment.

In the 1950's in connection with final confirmation of irregularity of the earth's rotation around its axis exact astrometric observation of the moon were of great value, and with them time can be determined independently, and consequently, it is possible to regulate rotation of the earth and, furthermore, to measure great distances on the earth's surface, which is of interest in geodesy. The most exact were photographic observations of the moon by means of a camera with a mobile filter, proposed by the American astronomer Markowitz. Regular observations of the moon at observatories of the USSR were organized in connection with the International Geophysical Year. Especially extensive work in this direction is conducted at Pulkovo by Kh. I. Potter, under whose guidance in the workshop of the observatory a special expeditionary astrograph was constructed. This instrument was used in several prolonged series of observations of the moon at Pulkovo and other observatories of the USSR. The Pulkovo astronomer N. F. Bystrov constructed the original photo-electrical instrument for automatic measurement of photographs of the moon, recording the results on punched cards for subsequent treatment on an electronic computer.

Finally, during the last few years a new direction in astrometric works began to develop rapidly — photographing and measurement on the photographs of the coordinates of objects moving rapidly across the sky: artificial earth satellites and space rockets. Fast cameras

with very exact registration of the moments of exposure were made for this. With these cameras on astronomical observatories and special stations extensive work is conducted on photographic observations of artificial satellites.

Let us turn to a survey of the work of observatories of the USSR on exact time service. This is the youngest branch of astrometry, existing around 50 years, since radio time signals began to be transmitted regularly. But in developing its attained accuracy of measurements it considerably outstripped other branches of astrometry. The time service has the practical functions of determination, keeping and circulation of the exact time.

Determination of time till now most frequently has been conducted by the astronomical method by means of observing the passage of stars through the meridian with the help of a transit instrument or photographic zenith telescope (during the last few years for this purpose observation outside the meridian with the Danjaune prismatic astrolabe have been used also). The astronomical time obtained from these observations is nonuniform due to the fluctuations of the speed of rotation of the earth around its axis, attaining several hundred millionths of a period (i.e., in 24 hours near 0.001 s). In contemporary requirements for accuracy of time determination this value is fully noticeable. Therefore during the last 10 years after the invention and introduction into operation of molecular and atomic standards of frequency, stability of which attains 10^{-10}, for determination of time continuously running quartz clocks began to be used also, the movement of which (frequency of quartz vibrations) is controlled by comparison with molecular and atomic standards. Comparison of atomic time with astronomical permits revealing interesting details in changes of the earth's rate of rotation, indicating the complex character of this phenomenon. In connection with the discovery of irregularity in the earth's rotation the idea about a unit of time is examined. Whereas earlier as the unit of time (second) 1/86400 of the mean solar day was taken, now it has been decided to start from the length of a year and determine the second as 1/31,556,925.9747 part of the tropic year for the epoch 1900.0.

Formerly time was kept by precision pendulum clocks placed in hermetically closed cases in deep vaults or thermostatic chambers, under conditions of constant temperature and pressure. Good stability of movement (almost to 10^{-8})[1] was demonstrated by free pendulum clocks. From approximately 1950 pendulum clocks have been displaced by the more exact, quartz clocks.

Time is communicated by means of radio signals. Earlier so-called rhythmic time signals were widely used (after 60 seconds 61 short pulses were transmitted), which upon aural reception coincided with, then separated from strokes of a chronometer, which permitted a sufficiently exact (better than 0.01 s) reception of signals without special equipment. Now along with rhythmic signals pulses are regularly transmitted on the radio every second from precise clocks, and sometimes radio transmissions of frequency signals are sent from a high-stability generator, allowing direct determination of the movement of the quartz clock. Contemporary automatic methods using an electronic counter or oscillograph permit taking time signals with a precision of 0.0001 s and more. Signals cannot move exactly at the assigned moment, therefore the most important problem of the time services regular reception of radio signals and corrections on the basis of astronomical observations. Work of the time services of various countries is coordinated by the International Time Bureau at the Paris Observatory, which from the material of the time services of various countries calculates and publishes the "final" times (of radio time signals), i.e., the final corrections of radio signals, fixing the official international standard time.

In the 1920's in Soviet Russia two time services functioned organized under the most direct participation of the Pulkovo Observatory, especially its director A. A. Ivanov (1867-1939), and the D. I. Mendeleyev[2] Leningrad Institute of Metrology and

[1]Accuracy in fractions of the measured time interval is considered.

[2]At that time the Main Board of Weights and Measures.

N. Kh. Preypich (1896-1946). The last also carried out important theoretical research in time measurement. To coordinate these works in the USSR in 1924 the Interdepartmental Time Service Committee was established at the Pulkovo Observatory under the chairmanship of A. A. Ivanov. P. A. Azbukin, heading the Leningrad Scientific and Testing Telegraph and Telephone Station, had a large role. In 1928 at Pulkovo calculation of the "final" times of rhythmic signals from the material of Soviet and certain foreign observatories was started.

In the 1930's in connection with wide expansion in the USSR of geodesic and gravimetric works several more time services were organized – in Moscow (at the P. K. Shternberg State Astronomical Institute and at the Central Scientific Research Institute of Geodesy, Aerial Photography Surveying and Cartography-TsNIIGAiK), at Tashkent, Kharkov and Nikolayev, where time signals in those years were sent from the Pulkovo, Moscow, and Tashkent observatories. The Soviet time service faced a difficult test in the years of the Great Patriotic War, when the majority of astronomical observatories was forced to cease work and the Moscow time services, evacuated to Sverdlovsk (GAISh) and Dzhambul (TsNIIGAiK), and also the Tashkent Observatory (V. I. Shcheglov) became responsible for providing the exact time to the country and the front. Thanks to radical reconstruction of work, introduction of new equipment and considerable intensification of astronomical observations, these three times services successfully coped with their responsible commission. In postwar years coordination of the USSR time services returned to Moscow, to the Committee of Standards at the Council of Ministers of the USSR, where now the standard time of the USSR is calculated and published, i.e., errors of radio time signals, obtained by combined treatment of materials from the USSR time services and certain other countries (at the present the USSR time standard is based on the materials of 17 time services). Now radio time signals are transmitted from Moscow; some of them are retransmitted in Irkutsk and Tashkent, thus ensuring the exact time throughout the USSR.

Much attention of the time service is given to the improvement

of equipment for sending and receiving signals and the comparison of timepieces. In the USSR original chronoscopes, electronic counters, oscillographic arrangements, electronic relay and many other instruments have been built and successfully used.

The biggest achievement of Soviet time services is the development and successful use of the photoelectrical method of recording star passages, thanks to which the accuracy of astronomical observations essentially increased. The photoelectrical method was first developed in 1933-1939 by N. N. Pavlov at the Pulkovo Observatory, where in 1939 it became the working method of astronomical observations of the time service. In 1955 Pavlov improved his own method by introducing a mirror grid and photomultipliers, which considerably increased the stability of registration and permitted stellar observations during unstable weather, in the twilight and in white nights. Afterward the Pulkovo Observatory ph oelectrical method began to be used in Moscow (V. E. Brandt), Leningrad, Nikolayev, Irkutsk, and now it is used in the observations of almost all Soviet time services.

Extensive work is being conducted in the USSR for the study and further improvement of instruments and on the study of subtle effects affecting the results of astronomical observations (thermal gradients in the body of the instrument and in ambient air, methods of shielding out their influences, refractional anomalies caused by different layers of the atmosphere, the effect of wind and others). At Pulkovo N. N. Pavlov constructed a photoelectrical transit instrument with closed pivots and thermal shielding, which significantly increased the accuracy of astronomical observations. An interesting improvement of the photographic zenith telescope was made at Pulkovo by V. A. Naumov, who reconstructed the system of time registration and introduced stored control. As a result the USSR created the first automatically working astronomical instrument for exact determination of time and latitude.

Work of the Soviet time services greatly intensified in 1957-1959 in connection with the International Geophysical Year. In these years equipment was essentially completed (quartz clock,

oscillographs, radio receivers, etc,), the program and methods of signal reception and astronomical observations were coordinated, and a single working list of stars was accepted. Above we already mentioned that on the basis of the huge material of observations obtained during those years, very exact catalogs of right ascensions of stars were composed (work of the Pulkovo, Leningrad, Moscow, Nikolayev and Irkutsk time services). A series of studies was carried out also on peculiarities of the earth's rotation for this period and on their connection with meteorological processes (the work of D. Yu. Belotserkovskiy in Moscow, V. I. Turenko in Kharkov, N. N. Pavlov and G. V. Staritsyna at Pulkovo). In particular, Pavlov arrived at the conclusion that the jump in the earth's rate of rotation observed in 1959 was caused by an anomalous temperature distribution on the northern hemisphere of earth (early spring), and this placed in doubt the hypothesis expressed abroad on the dependence of the earth's rate of rotation on solar activity. The discussion of materials obtained by the time services for 1957-1959 still has not been completed; we can expect that it will give new interesting results.

Let us consider now the basic work of the latitude service. A change of latitudes induced by movement of the axis of rotation in the body of the earth was revealed from observations in the 1880's. Soon was clarified the complex character of this phenomenon, in which two periods overlapping each other were discovered. The main period — of 428 days, or the period of free nutation, turned out to be much longer than the theoretical period of 305 days, derived in 1790 by L. Eyler for a rigid earth; thus it was proven that the earth is an elastic body. The second — an annual period, as was clarified subsequently — is induced and is basically explained by seasonal shifts of air masses of the earth's atmosphere. The full swing of changes of latitudes induced by the movement of the pole does not exceed 0".8 or 25 m on the surface of the earth. For a detailed study of this subtle phenomenon at the end of past century the International Latitude Service was organized (ILS) with several observation stations located on one parallel +39°8' and equipped with the same kind of zenithal telescopes. One of them was built in

Russia at Chardzhov (Central Asia), where it functioned up to 1919. In 1929 a new ILS was put into operation at Kitab, and recently noted its 35th anniversary of successful activity. The work of ILS stations is coordinated by the Central Bureau of the ILS, where combined treatment of observations is conducted and polar coordinates are calculated.

The exact latitude of a place must be known in the absolute determinations of the declinations of celestial bodies, therefore certain observatories, working in fundamental astrometry organized among themselves an independent latitude service, i.e., regular latitudinal observations with a zenith telescope.

At the Pulkovo Observatory a zenith telescope made in the workshops of the observatory by mechanic Freyberg was set up for this purpose in 1904. It turned out to be a first-class tool for investigating changes of latitude. In 60 years of regular operation around 100,000 high-precision observations have been obtained with it (average error of one latitude determination is around ±0".15). One of the problems before the Pulkovo latitude service was the investigation of brief periodic variations of latitude, which could not be made by ILS stations because of their program of observations. For this purpose at Pulkovo from 1915 to 1929 (subsequently from 1955 to 1961) observations were conducted on an expanded program, i.e., all night – "from dawn to dawn" from which indeed it was possible to determine the diurnal term, true with an amplitude only of several hundredths of a second of an arc (work of V. R. Berg, S. V. Romanskaya and others).

In 1926 the initiative of A. Ya. Orlov (1880-1954) provided the basis of an astronomical and gravimetric observatory in Poltave, the plan of whose works included investigations of changes of polar latitude and motion, as well as the study of diurnal variations. For this purpose night and day observations were undertaken with the zenith telescope for two bright zenith stars – α-Perseus and η-Ursa Major – culminating approximately twelve hours after one another. Observations of these stars through many years permitted N. A. Popov to derive not only the diurnal term, but also small corrections to nutational terms of a short period, testifying

Aleksandr Yakovlevich Orlov

1880-1954

to the presence of a liquid nucleus in the center of the earth. From an analysis of a 23-year series of observations of two zenith stars Popov in 1963 first revealed "diurnal nutation," i.e., minute periodic motion of the pole, the period of which (somewhat shorter than twenty-four hours) was theoretically derived by M. S. Molodenskiy in his thorough investigations of the rotation of an earth with a liquid nucleus. In many works of Soviet "latitude specialists" questions were examined about secular motion of the pole and about nonpolar, i.e., not depending on polar motion, changes of latitudes. A. Ya. Orlov offered a simple formula for showing slow nonperiodic changes of latitude from observations; these changes turned out to be of nonpolar origin, inasmuch as at various observatories the measurement results deviated. In 1954 as a result of thorough analysis of ILS materials it was possible to determine secular motion of the pole, directed along the meridian 69° west from Greenwich and amounting to around 10 cm a year. The results of Orlov subsequently were confirmed by other authors.

The Soviet "latitude specialists" allotted much attention to instruments and the improvement of programs and methods of observations, inasmuch as this determines reliability and accuracy of the obtained results. Ye. P. Fedorov developed a new economic program of latitude observations, intended for the study not only of periodic but also secular motion of the pole. This program is being successfully used in the Poltava and certain other observatories. Latitude investigations in the USSR were activated in the 1950's in connection with the discovery of irregularity of earth's rotation and the intensified operations in the time services, necessary to know the polar coordinates. Regular determinations of latitude were organized also in Kazan (observatory named after V. P. Engelhardt), Moscow (GAISh), Irkutsk and Gor'kiy. In 1953 for a generalization of materials obtained by the USSR latitude services and rapid calculation and communication to interested departments of approximate polar coordinates the Soviet Latitude Service was organized (SSSh) with its center at the Poltava Observatory. The SSSh successfully developed its operations and as of the present time have accumulated interesting experiences. It is possible to note that in three years (in 1956) the analogous International Routine Service was organized (SIR) at the Paris Observatory.

A further stepping up of latitude studies in the USSR and other countries took place in 1957 in connection with the International Geophysical Year. In Leningrad at the State Optico-Mechanical Plant a series of large zenith telescopes ZTL-180 was made, which now are equipment at almost all observatories of the USSR – the leader in observations. The new instruments gave results of very high accuracy. At several observatories (Poltava, Irkutsk, Novosibirsk, Pulkovo) observations with the Danjaune prismatic astrolabe, and at the Poltava Observatory, furthermore, an interesting experiment on polar motion by means of azimuthal observations with a transit instrument has been set up.

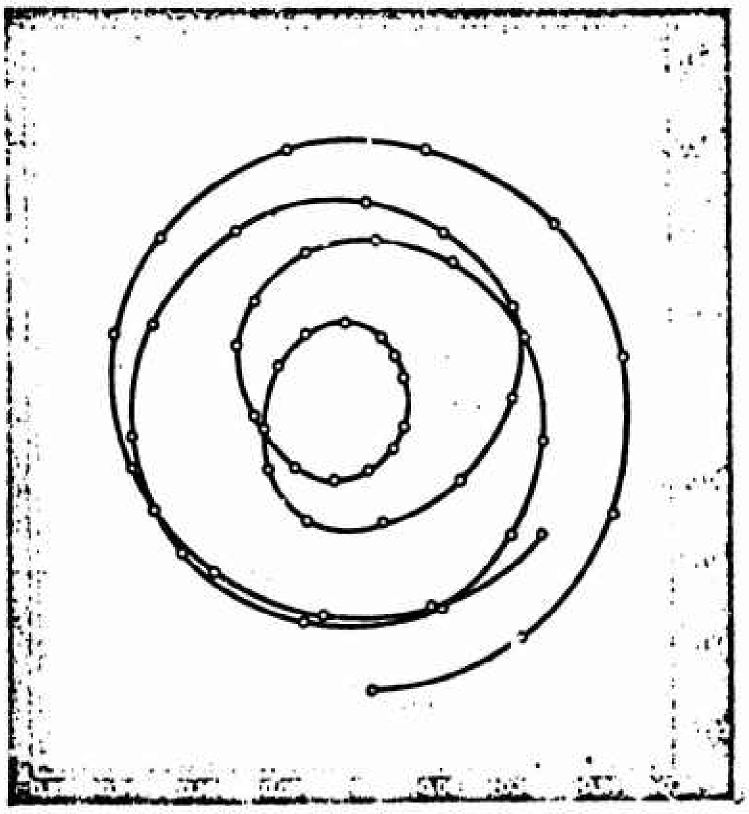
Although the methods of astronomical observations used in latitude services give results which had little dependence on instrument error, nonetheless, a detailed investigation of instruments

is the most important problem of observers. In connection with this there is special interest in parallel observations on two or more instruments of the same observatories, which, as it turns out, never show an agreement of results due to fine instrument and human errors which cannot be considered. Parallel observations on two zenith telescopes have already been conducted at the Poltava Observatory for more than 20 years, and in recent years also at Pulkovo and Kitab.

A big event for the Soviet latitude service was the organization of the Pulkovo Observatory Far Eastern Latitudinal Station at Blagoveshchenska-na-Amure. The question about this was considered and prepared over many years, starting with the above-mentioned astrometric conference in 1932. At Blagoveshchenska-na-Amure there is now a zenith telescope ETL-180 with which from 1959 more than 12,000 high-precision determinations of latitude have already been obtained. With the annexation of the Blagoveshchenska station, which stands on a 90° longitude from European observatories, the weight of the polar coordinates calculated at Poltava according to the SSSh, increased four times.

The great amount of material on latitude observations obtained by Soviet and foreign observatories in 1957-1959 now is being investigated in detail in a study of pole motion during this time to show nonpolar components in changes of latitude, brief periodic terms, the influence of meteorological factors, the effect of wind and others, and also to clarify the true accuracy of latitudinal observations and polar coordinates obtained from them.

A series of interesting studies on these questions has already been published (the work of Ye. P. Fedorov, V. I. Sakharov and others). But studies on increasing the accuracy of astronomical observations is a year-long process; the problem will occupy astronomers of not only our, but also the following generation. After all, there is a number of unsolved problems, such as secular motion of the pole, mutual shifts of the continents and others, which require observations lasting many decades. The value of exact astrometric observations frequently increases as epochs become a thing of the past, and



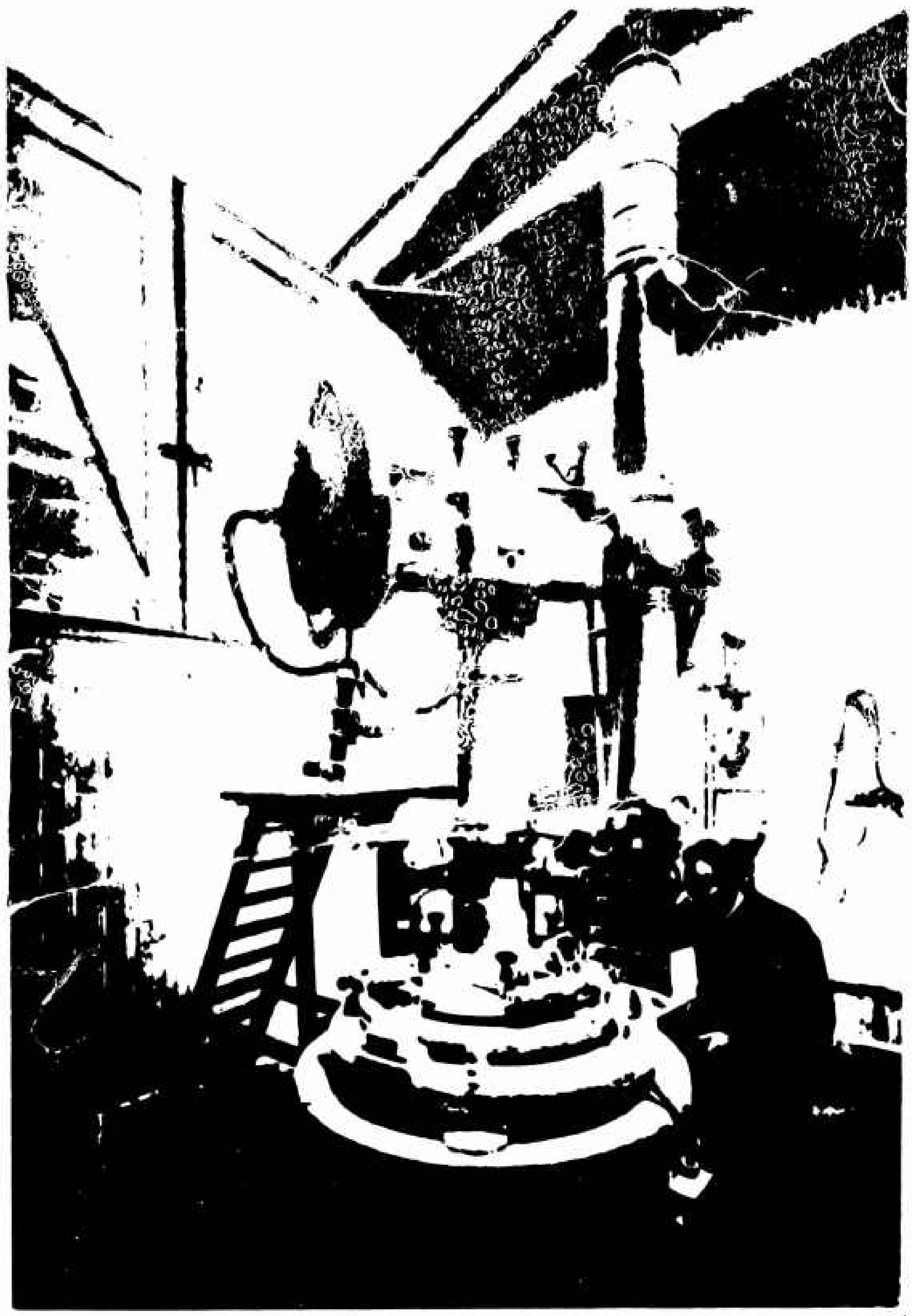
Curve of polar motion from 1959 to 1964 according to the Soviet Latitude Service.

GRAPHIC NOT REPRODUCIBLE

consequently, these observations are needed not only for problems posed during their organization, but also are a reserve for future investigations.

We have yet to mention certain work on use of the methods of astrometry to determine basic astronomical constants. These works have always occupied a conspicuous place in the activity of the Pulkovo, Moscow and certain other observatories. Even at the end of the 1920's at Moscow with the active participation of N. N. Pariyskiy extensive work was carried out on determining constant precession from an analysis of the proper motions of stars taking into account their parallaxes, the sun's motion and rotation of the galaxy. Among the works on nutational motion of the earth's axis we will mention the determination of constant nutation made by K. P. Kulikov (GAISh) from an analysis of Pulkovo latitudinal observations with the xenith telescope, and an extensive study on nutation and forced motion of the pole, recently carried out by Ye. P. Fedorov (Poltava – Kiev) on the basis of detailed processing of years of material from the International Latitude Service.

The new value of constant nutation obtained by Fedorov (9".198) is the most reliable and exact of all the latest determinations. Regarding constant aberration, now it frequently is determined in the analysis of a large series of meridian and latitude observations (the work of V. R. Berg, S. V. Romanskoy, A. A. Nemiro and others).



The great zenith telescope ZTL-180 of the Pulkovo Observatory.

In the restored Pulkovo Observatory in 1952 a new instrument by A. A. Mikhaylov was seen – the polar telescope. It is a fixed astrograph directed towards the celestial pole, intended for photographing the traces of circumpolar stars to determine the constants of aberration and nutation. The instrument was thoroughly investigated and improved by Kh. I. Potter. With the polar telescope a new value of constant aberration has already been obtained, which turned out to be very close to the recently accepted international value.

Two astronomical constants – solar parallax and constant of aberration – are rigidly connected by a simple mathematical relationship, which also contains the velocity of light. As it is known, during the last few years in the United States, England and the USSR radar observations of Venus and other planets were successfully carried out, that permitted obtaining the solar parallax with a precision exceeding the best astronomical results by tens of times. Now a continuation of work on the determination of the solar parallax and constant of aberration by methods of astrometry should be examined only from the point of view of their methodical value. Inasmuch as stars describe aberrational ellipses over a year, the value of the constant of aberration derived from observation of stars allows judgement of seasonal systematic errors of astronomical observations that by itself has an important value.

Work on the determination of astronomical constants can include also studies of the figure and rotation of the moon in particular lunar libration; this is being done in depth in Kazan at the V. P. Engelhardt Observatory and in Kiev (A. A. Yakovkin, A. A. Nefed'yev, Sh. T. Khabibullin and others). Finishing the survey of Soviet astrometric works, we note that in the USSR a number of monographs and training aids on astrometry has been published (S. N. Blazhko, N. I. Idel'son, M. S. Zverev, K. A. Kulikov, V. V. Podobed, S. A. Kazakov, Ye. Ya. Bugoslavskaya and others).

We already indicated that the astrometric conference of 1932 was a critical point in the development of Soviet astrometry, that this conference began the unity of forces of our astrometerists

around basic problems and that a series of large collective works was outlined, which subsequently became international. This direction obtained further support in 1937, when in the system of the Academy of Sciences of the USSR a coordinational organ was established — the Astronomical Council and its branch commissions, including the Astrometric Commission, which became the leading and advisory center for astrometric work in the USSR. The commission met regularly (in the beginning yearly, subsequently every 2-3 years) to call conferences for the discussion of plans and reports of observatories, the progress of collective works, and also for discussions of pressing problems in astrometry. Starting with the tenth conference (December, 1952) the "Transactions" of astrometric conferences of the USSR are published, which now have become the collective printing organ of Soviet astrometrists.

Besides conferences on different problems of astrometry, in 1939 the initiative of Soviet "latitude specialists" led to latitude conferences, the "transactions" of which also will be published. In 1960 in connection with the stepped up development in the Soviet Union of work in the time service and latitude service the Astrometric Commission branched into a new Astrocouncil commission — the Commission for Study of the Earth's Rotation.

Prior to 1948 the ties of Soviet astrometrists with foreign observatories were limited to the participation of the time services of the USSR in the work of the International Time Bureau, participation of the Kitab latitude station in the work of The International Latitude Service and the personal membership of a few Soviet astrometerists in the International Astronomical Union and in the German Astronomical Society. In postwar years these ties rapidly expanded. At the VIIth Congress of the IAU in Zurich (1948) a resolution was accepted approving the Soviet plan of photographic observations of remote galaxies, and the following, VIIIth Congress in Rome (1952) approved the problem on creation of a Catalog of Faint Stars.

The subsequent broad international expansion of meridian and photographic observations connected with the composition of the KSZ,

Aleksandr Aleksandrovich Mikhalov at the zenith telescope.

and also the approval of the Xth Congress of the IAU at Moscow of new programs of meridian observations proposed by Soviet astronomers already was mentioned above.

Thus, it is possible to ascertain that now all the work of USSR observatories on meridian astrometry and a considerable part of work on photographic astrometry are conducted in the plan of broad international collaboration, a good example of which is the work of the expedition of the Pulkovo Observatory to Chile. The International Geophysical Year promoted the expansion of collaboration in the time service and latitude service. Observatories of the USSR, leading in latitude observations, system of International service term at the Paris Observatory, where now not only the material from the time services regularly are sent, but also the results of latitude observations. We note the general high activity of Soviet astrometrists in the International Astronomical Union; now more than 30 of them are members of the IAU and A. N. Deych, M. S. Zverev, A. A. Mikhaylov, A. A. Nemiro, N. N. Pavlov and Ye. P. Fedorov at various

times were or are now presidents or vice presidents of astrometric commissions in this international organization.

The Pulkovo astrometric school even in the last century gained international authority by its outstanding work on the star catalogs and on the determination of astronomical constants. The Soviet astrometric school, continuing and expanding the best traditions of the Pulkovo school, conducts work on a much wider scale, in accordance with the growth of requirements of a rapidly developing science and technology.

CELESTIAL MECHANICS

Celestial mechanics is that branch of astronomy studying the movement of bodies in the solar system. Problems of celestial mechanics can be divided into four large groups.

1. Development of general questions of planetary motion in a gravitational field (so-called problem of bodies, a special case of which is the famous three-body problem).

2. Development of mathematical theories of the motion of specific bodies of the solar system (planets, satellities, comets).

3. Comparison of theoretical research with astronomical observations, and thus, the determination of the numberical values of different astronomical constants (elements of orbits, mass of planet, constants connected with rotation of earth, constants characterizing figure of earth and its gravitational field and others).

4. Composition of astronomical ephemerides (astronomical almanacs), which concentrate the results of theoretical research in the region of celestial mechanics (and also in adjacent areas — astrometry, stellar astronomy, experimental physics, geodesy and others) and fix at every instant t the fundamental space-time system of reference necessary for all sciences dealing with the measurement of space and time.

Astronomical almanacs find wide application in practical problems of astronomy, geodesy and cartography; they ensure naval ("Naval astronomical almanac") and air ("Aviation astronomical almanac") navigation; they are necessary for launching artificial earth satellites and spaceships.

Development of celestial mechanics in the Soviet Union is closely connected with the activity of two scientific centers, appearing directly after the Great October Socialist Revolution: the Institute of Theoretical Astronomy of the Academy of Sciences of the USSR in Leningrad and the Department of Celestial Mechanics of Moscow State University. These two centers formed Leningrad and Moscow schools, which determined the development of celestial mechanics in the Soviet Union for 50 years.

At Leningrad questions of celestial mechanics were developed mainly in connection with those practical problems which were set before the Institute of Theoretical Astronomy at its organization in 1919 (composition of astronomical almanacs, calculation of ephemeris of a minor planet). At Moscow the dominating influence for many years was the cosmogonic problem.

Institute of Theoretical Astronomy

The Institute of Theoretical Astronomy of the Academy of Sciences of the USSR at Leningrad was the only specialized scientific establishment on theoretical and applied questions of celestial mechanics in the Soviet Union.

Abroad there is only one scientific establishment, which in profile and scope of subject area approximately corresponds to the Institute of Theoretical Astronomy – the Bureau of the American Ephemeris in the United States. The activity of similar establishments in England, France and the FRG is limited to a considerably narrower circle of problems.

The Institute of Theoretical Astronomy began its activity

7 October 1919 as the Calculating Institute in the All-Russian Astronomical Union. It was organized due to the initiative of the outstanding Soviet scientist B. V. Numerov (1891-1943), one of the greatest Soviet specialists in celestial mechanics, astrometry and gravimetry.[1] In January, 1920, B. V. Numerov was made director of this institute, renamed the State Calculating Institute; in 1923 it combined with the Astronomical and Geodesic Institute (organized in 1920) and became the Astronomical Institute. Besides organizing the institute's publication of almanacs and different ephemerides Numberov in particular made a great contribution to the development of simpler and practically convenient numerical methods of determining the orbits of the minor planets and comets. His results, published in a large work in 1923, composed the basis of further investigations of the institute, which he directed until November, 1936, when his scientific activity tragically broke off. In 1939 the Astronomical Institute was transferred to the Academy of Sciences of the USSR.

In December, 1942, M. F. Subbotin (1893-1966) was named director of the Astronomical Institute. Subbotin was a great specialist in celestial mechanics, well-known first of all thanks to his own

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[1]Boris Vasil'yevich Numerov was born in Novgorod in 1891 graduated in 1913 from Petersburg University and, leaving the Department of Astronomy, simultaneously began to work at the Pulkovo Observatory. In 1924 he was made a professor of theoretical astronomy at the University and of geophysics at the college of Mines. Besides the directorship of the Astronomical Institute, from 1926 to 1928 he headed the Main Geophysical Observatory, and in 1931-1933 managed the Department of Applied Mathematics of the State Optical Institute in Leningrad. In 1929 he was chosen a Corresponding Member of the Academy of Sciences of the USSR.

B. V. Numerov carried on general scientific and organizational work as chairman of the Russian Astronomical Society (1922-1926) and chairman of the Astronomical Committee of the Narkompros of the RSFSR (1930-1934), coordinating scientific work and teaching astronomy. During numerous foreign missions in the 1920's and 1930's to Germany, England, Holland, France and the United States Numerov introduced a great contribution to the cause of restoration and of the damage from the first world war and breaking the blockade of scientific communications of the RSFSR (and then the USSR) with other countries.

Boris Vasil'yevich
Numerov

1891-1943.

fundamental three-volume handbook "Course of Celestial Mechanics" (1933-1949), several generations of Soviet specialists have studied.

In October, 1943, the Presidium of the Academy of Sciences of the USSR resolved to place the Astronomical Institute in charge of scientific research work in the area of celestial mechanics and the composition of astronomical almanacs, for which the Astronomical Institute was renamed the Institute of Theoretical Astronomy. Subbotin remained at the head of the institute until August, 1964, when was forced to leave this post for reasons of health.

During those years the institute advanced into the number of leasing astronomical establishments of our country.

Mikhail Fedorovich
Subbotin

1893-1966

Let us consider the basic problems which have occupied and continue to occupy the collective of the Institute of Theoretical Astronomy.

The Problem of Three Bodies. Questions of the Convergence of Series

The beginning of the twentieth century was marked by considerable progress in the area of celestial mechanics. This progress is connected first of all with the work of A. Puankare on periodic orbits and with the work of the Finnish astronomer Sundman, who succeeded in solving the general three-body problem (i.e., the problem of motion of a planet in the field of gravitation of not only the sun, but also a certain other planet which perturbs the elliptical motion of the first) using an infinite exponential converging series.

At the Institute of Theoretical Astronomy in 1925 a special seminar directed by V. I. Smirnov and A. A. Markov was organized to study these works. Many Leningrad astronomers and mathematicians participated in the work of the seminar. The result of the activity of the seminar was original research in different theoretical problems of celestial mechanics.

From 1926-1933 Markov solved certain special cases of the three-body problem and studied characteristic properties of the motion of three bodies near moments of collisions.

In these years N. S. Yakhontov studied critical points in the problem of two and three bodies. These investigations permitted him to solve the current problem of celestial mechanics about improving the convergence of expansions representing the coordinates of points as a function of time. Yakhontov showed that instead of time the introduction of functions regularizing simple collisions as an independent variable considerably increases rapidity of convergence of series. This variable was then used for calculation of perturbations according to the method of K. Bolin.

The very important problem for celestial mechanics about intensifying the convergence of expansions in theories of planetary motion remains even now a current problem in theoretical astronomy. In 1947 Subbotin found new ways to solve this problem, founded on very general properties of trigonometric series representing analytic functions. The new expansions possess sharper convergence than those used earlier, and their use for practical calculations is facilitated by special auxiliary tables.

The lack of practical applicability of Sundman's power series due to their too slow convergence makes very urgent the problem of modification of these series to accelerate their convergence. Important results were obtained in 1963 by the Soviet astronomer V. A. Brumberg. He constructed series of polynomials whose effectiveness for a certain finite interval of time has been checked

in practice using electronic computers. Independent of initial data, universal factors of convergence were successfully calculated, with whose help from coefficients of the standard Taylor series coefficients of series of polynomials can be obtained. Coefficients of Taylor series are calculated recursion formulas, obtained by reducing the right sides of equations to quadratic functions relative to the unknown coordinates.

Questions of convergence of Hill series in the theory of the moon's motion attracted the attention of A. M. Lyapunov. In 1896 he showed convergence of these series if the small parameter in which the expansion is in $|m| \leq 1/7 = 0.1428...$ For the moon $|m| = 0.0808...$, which is less than the limit found by Lyapunov. In 1952 the Leningrad astronomer G. A. Merman proved convergence of Hill series when $|m| \leq 0.18$, which considerably expaned the limits of convergence set by Lyapunov. This in particular ensured the convergence of series in theory of motion of the eighth moon of Jupiter, developed by V. F. Proskurin in 1950. For this moon $|m| = 0.146...$, which is larger than the limit of Lyapunov, but less than Merman's limit. In 1959 this work was continued by M. S. Petrovskoy, who generalized the methods of Lyapunov and Vintner and proved the convergence of Hill series for $|m| < 0.21..$ An estimated remainder was given for different important cases.

Question of series convergence in celestial mechanics are closely connected with the so-called problem of small divisors. The mathematical difficulties of this problem in considerable degree are overcome in the work of Soviet mathematicians of the A. N. Kolmogorov school. The basic idea of these works is the use in place of series in powers of the masses involved consecutive canonical transformations, which were used in the same form in celestial mechanics even at the end of the XIXth and beginning of the XXth centuries by S. N'yukom and A. Puankare. But, moreover, in every approximation a set of frequencies is excluded, corresponding to the small divisors, which tend to zero to fast. This method, shown for the first time by N. Kolmogorov in 1954, was then strictly substantiated by his pupil V. I. Arnol'd.

In works of 1962-1964, dedicated to the problem of stability of the solar system, Arnol'd overcomes difficulties appearing due to the slow rotation of the line of apses and the nodal line of planet orbits by using averaging and extends his results to the two-dimensional problem of three bodies and to the problem of n bodies for the case of small eccentricities and small inclinations of orbits (and also under the condition that the planetary masses are small as compared to mass of the sun). The work of A. N. Kolmogorov and V. I. Arnol'd was honored by the Lenin Prize in 1965.

From the theory of periodic orbits the Institute of Theoretical Astronomy essentially new results obtained. An interesting class of periodic solutions of the bounded three-body problem, and also the Hill problem was found in 1961 by G. A. Merman. For the general three-body problem a new class of periodic solutions was obtained by Yu. V. Batrakov (1955).

In connection with O. Yu. Shmidt's work in cosmogony in the 1940's, questions of the study of final motions in the three-body problem caused great interest. By final motions are understood those maximum motions which take place when $t \to +\infty$ or when $t \to -\infty$. By numberical integration Shmidt showed the possibility of capture by the sun of aprctoplanetary gas-dust cloud with the help of an auxiliary star.

This result contradicted the theorem of Shazi (1932) about the impossibility of capture in the case of nonnegative values of constant energy ($h \geq 0$). However, numerical integration in the problem of O. Yu. Shmidt, carried out by N. N. Pariyskiy, still was not strict proof.

Such proof was given soon in the work of G. F. Khil'mi. There was further development of these questions at the Institute of Theoretical Astronomy in 1953 in work of G. A. Merman. In 1961-1962 he found a stronger criteria of the possibility of capture in hyperbolic and parabolic cases of the three-body problem. Analogous

criteria, more refined in certain cases, have been proposed by the Moscow mathematician V. M. Alekseyev. He examined certain new examples of capture and exchange. G. A. Merman (1954) also improved and essentially supplemented certain theorems of Shazi. He strictly proved the impossibility of capture in the case of negative values of constant energy.

From a new point of view V. A. Bromberg (1962) studied the determination of orbits, which he set up as a boundary value problem and solves by the direct variational method of the steepest descent. Of great interest also is his work of 1961, in which he investigated the probability distribution of coordinates and speeds (or elements of orbits) for an instant according to an assigned probability distribution of initial data and parameters examined as random variables. It is strictly proven that there exists a finite limit for t, with which error is determination of average anomaly attains 2π and its determination for large t becomes impossible

The theoretical works of V. F. Myachin (1959-1964) on estimating error in methods of numerical integration have an important value. In 1963 he was able to strictly substantiate a well-known result of the American astronomer D. Brauer or error growth during numberical integration in proportion to $n^{3/2}$, where n is the number of steps of integration. In these works the question about optimum selection of the integration step is solved.

In conclusion we will note an interesting work of the Soviet astronomer M. D. Polanuyer, who is 1964 on the basis of the method of Lindstedt proposed a new theory of libration of the moon, free, in contrast to the classical theory, from resonance terms.

Fundamental Constants Connected with the Earth

The Institute of Theoretical Astronomy has carried out much research in the development of a method of determination of fundamental constants connected with the earth. The problem of establishing a

rational system of astronomical constants from a minimum number of basic parameters, on the basis of which for any instant it is possible to calculate the position and motion of bodies of the solar system with the necessary accuracy, composes an extraordinarily important and at the same time extremely complex problem of astronomy.

This problem is still far from being solved and systems of such constants established from time to time (the last system of astronomical constants was accepted by the International Astronomical Union in 1964 at the XIIth Assembly in Hamburg) require periodic reconsideration and definitization in connection with the improvement of methods of observations and their treatment, accumulation of data of observations or the increase of the number of interesting objects.

Among other constants a special place always belongs to constants connected with the earth, since its surface is the base for observations of all celestial bodies. The predominant influence of the earth's mass on artificial bodies launched from its surface and moving near it has placed the fundamental constants connected with the earth into a series of the most important parameters necessary not only for astronomy, but also for cosmonautics.

In 1952 in the "Transactions of the Institute of Theoretical Astronomy" (Issue III) was printed a large monograph of I. D. Zhongolovich "The external gravitational field of the earth and fundamental constants connected with it." This work was an essential step in developing the problem of astronomical constants and became well-known in the Soviet Union and abroad. To obtain numberical results the determinations of gravity known at that time in approximately 26,000 gravimetric points were used. Considerable methodical difficulties resulted from the extraordinarily nonuniform distribution of these observations, in which over huge spaces, especially in the southern hemisphere and on the oceans, they were completely absent. The basic result of the work was resolution of the force of gravity in spheric functions to the eight order with determination of numerical values of 81 coefficients of this expansion.

For comparison we indicate that in the work of the well-known English geophysicist G. Jeffreys (1942) as a result of analogous expansion only 13 numerical coefficients were determined.

Thus, the work of Zhongolovich disclosed new values of the series of basic parameters characterizing the earth, the figure of the geoid is determined and general maps of heights of the geoid for the whole surface of the earth are worked out. Finally new data on the distribution of gravitational force on the earth's surface permitted obtaining a general expression of the potential of terrestrial gravity outside the surface of the earth.

A work of I. D. Zhongolovich "The potential of terrestrial gravity" appeared in 1957 shortly before the launching of the first artificial earth satellite and was a valuable source of data of important value for calculations connected with the motion of artificial space bodies.

In 1956 the "Transactions of the Institute of Theoretical Astronomy" (Issue VI) contained another extensive work of I. D. Zhongolovich – "The determination of dimensions of the general terrestrial ellipsoid" – which was a natural supplement and continuation of the 1952 work. It develops a method of obtaining dimensions (large semiaxis) of the general terrestrial ellipsoid according to different astronomical and geodesic works on the mainlands. The treatment of observations according to the scanning method and a new method of projection is examined. For numerical applications published data about deviations of plumb lines in approximately 1000 points in the territory of the United States and Canada are used and also data on degree measurement of the so-called Struve Arc. In this last case it was necessary to conduct a thorough historical investigation about the interrelation between the toise and the meter.

Parameters of the gravitational field of the earth can be determined by the perturbations of orbital elements of artificial satellites (see § 7), but it is also possible to use artificial satellites for purely geodesic aims, for determination of coordinates

of points on the earth's surface, to connect different geodesic systems among themselves and in the end to determine the dimensions and shape of the earth. These questions are examined in detail in "Earth satellites and geodesy" I. D. Zhongolovich (1961).

Motion Theory of the Planet Pluto

The most distant planet of the solar system, Pluto was discovered 21 January 1930 at the Lovell Observatory in the United States. With the entry of new data of observations the ephemerides of Pluto were calculated for the preceding years. By these ephemerides on old photographs it was possible to show the photography of Pluto starting from 1914.

In 1935 the French astronomer Ruhr [Translator's Note: exact spelling not found] began to rublish extensive work on the analytic theory of the motion of Pluto, using Hill's method in the form given by Anduaye [Translators Note: exact spelling not found]. However, this work was not finished. He calculated only four intermediate orbits of Pluto.

In 1946 by the initiative of M. F. Subbotin the Institute of Theoretical Astronomy began work on an analytic theory of the motion of Pluto. This fundamental investigation was carried out under the leadership of M. F. Subbotin and Sh. G. Sharaf and was successfully completed in 1963.

In the Soviet Union work of such a character was first carried out.

The analytic theory of the motion of Pluto was constructed on the basis of the Laplace-Newcom classical method which completely justified itself during the construction of the theory of motion of the major planets. Perturbations from Neptune are obtained by numerical integration.

The theory of motion of Pluto was published in Issues IV and X of "Transactions of the Institute of Theoretical Astronomy."

The Moons of Jupiter

The discovery in 1908 of the eighth moon of Jupiter played, as is well-known, a large role in the development of methods of numerical integration. Perturbations of this satellite from the sun are so great that it turned out to be more convenient not to calculate perturbations of osculating elements, but to integrate directly equations of motion of natural and artificial bodies of the solar system. The eithth moon of Jupiter was observed rather regularly until 1923, after which it was lost, so the ephemerides of the moon calculated in the United States turned out to be inaccurate. In the 1920's development of the theory of motion for the eighth moon was started at the Institute of Theoretical Astronomy. N. F. Boyev, taking as initial data the coordinates of the moon in 1916, carried out numerical integration of equations of motion of the eighth moon up to 1930 by the method of B. V. Numerov. By its ephemerides the moon constituting an extremely weak object of the 18th stellar magnitude, attainable only by large instruments, was again found in the United States, after which its observations were not interrupted until 1942, when it again was lost. D. K. Kulikov started extensive work on the presentation of all observations of the moon from 1908 to 1942. He used the method of Cowell for numerical integration in rectangular coordinates and successfully solved the problem. The moon was found again from its ephemerides in 1947. Simultaneously D. K. Kulikov obtained a new value for the mass of Jupiter, which is in good agreement with other contemporary determinations. In this work D. K. Kulikov made the first detailed study of the effect of perturbations on coefficients of conditional equations.

In 1950 V. F. Proskurin gave a detailed analysis of all work on the motion of the eighth moon of Jupiter and showed that the method of constructing an exact analytic theory of the motion of this moon proposed by K. Brown and D. Brouwer is unsuccessful. In

connection with this he calculated the basic inequalities by the method proposed by J. Hill in the theory of the moon's motion. This method in 1956 was successfully used by S. S. Tokmalayevaya in working out the analytic theory of motion of the eighth moon of Jupiter.

The theory of motion of the sixth moon of Jupiter was worked out in 1955 by V. F. Proskurin. He used for this the literal decomposition of C. Delaunay (France) in the theory of the moon's motion.

Artificial Earth Satellites

The launching of the artificial earth satellites set before the Institute of Theoretical Astronomy new responsible problems. These problems exceeded the limits of classical celestial mechanics, since motion of artificial satellites has a series of essential peculiarities as compared to motion of natural bodies of the solar system. First of all, motion of artificial earth satellites occurs not only under the influence of gravitational forces, but also of resisting forces, caused by the presence of the atmosphere.

Furthermore, thanks to proximity of orbits of artificial earth satellites to the surface of the earth insufficient accuracy in calculating the figure of the earth and anomalies of the gravitational field cause a deviation of satellite motion from theoretical calculations.

Acting simultaneously, all these causes extraordinarily complicated theoretical research of the motion of artificial earth satellites. On the other hand, peculiarities of the motion of artificial satellites cause certain difficulties in organizing their observations. The rapid angular displacement of a satellite with respect to the observer makes impossible the application of the usual astronomical instruments and classical method of observations.

We will examine certain questions of the method of treating optical observations of artificial satellites used at the Institute of Theoretical Astronomy.

The basic mass of all optical observations is made up to ... visual, and also preliminary photographic observations. They have a low accuracy and give coordinates of a satellite in the sky with error of the order of 0.1-0°.2 and moments of observations with an accuracy of $0^{s}.1$. The basic purpose of such observations is to predict the motion of satellites.

A considerably smaller portion is exact photographic observations, which make it possible to determine the position of a satellite on the celestial sphere accurate to 0".1, and moments of time accurate to $0^{s}.01$ and greater. Such observations permit obtaining the orbital elements of a satellite with increased accuracy.

V. F. Proskurin and Yu. V. Batrakov in 1958-1959 developed a sufficiently full analytic theory of the motion of satellites in the field of gravitation of the earth, and also a method of calculating atmospheric drag. In this theory expressions for osculating elements accurate to the first order of oblateness of the earth have the form[1]

$$\begin{aligned}
a &= a_0 + \Sigma a_{ik} \cos(iM + k\omega), \\
e &= e_0 + \Sigma e_{ik} \cos(iM + k\omega), \\
i &= i_0 + \Sigma i_{ik} \cos(iM + k\omega), \\
\Omega &= \Omega_0 + \Omega' t + \Sigma \Omega_{ik} \sin(iM + k\omega), \\
\omega &= \omega_0 + \omega' t + \Sigma \omega_{ik} \sin(iM + k\omega), \\
M &= M_0^0 + M_0' t + \Sigma M_{ik}^0 \sin(iM + k\omega).
\end{aligned} \tag{1}$$

[1]In the right sides of equations (1) the mean anomaly of a planet M and the argument of the perehelion ω are calculated by the formulas of undisturbed motion, i.e., are known functions of time.

where coefficients a_{ik}, e_{ik}... depend on constants a_0, e_0, i_0 and are series in powers of a small parameter. Orbital inclination i_0 is in the coefficients of these series in the form of finite trigonometric expressions.

This theory is assumed to be the basis of treatment of optical observations of artificial satellites.

The case of small eccentricities, which are very frequently encountered in practice, presents certain difficulties and is examined in the work of C. A. Chebotareyev (1962).

Since atmospheric drag causes considerable perturbations of mean daily motion, which cannot as yet be determined theoretically, then in the expression for mean anomaly of an artificial earth satellite empirical terms proportional to time are introduced, the coefficients of which are determined from the totality of conditional equations simultaneously with orbital elements.

Several programs are composed for the treatment of observations. The most full program permits determining six corrections to elements of elliptic motion, and also secular perturbations in the node of an orbit and in the mean anomaly. Systems of elements of artificial satellites obtained at the Institute of Theoretical Astronomy are published regularly in the "Bulletin" of stations for optical observation of artificial earth satellites (G. A. Chebotarev, Ye. N. Makarov). Results of the treatment of optical observations of artificial earth satellite make it possible first, to examine contemporary ideas about the upper atmosphere and, secondly, to increase considerably the accuracy of determination of parameters of the gravitational field of the earth. As it is known, resistance of air causes secular variation of the inversion period of a satellite, and the gravitational action of oblateness of the earth according to (1) causes secular motion of nodes and perihelion of the satellite orbit. These secular variations can be used for determination of air density and oblateness of the earth.

Determination of density of the upper atmosphere by the motion of a satellite is the subject of the work of A. M. Fominov (1963-1964), using a new model of nonspherical and nonstationary atmosphere with a simple analytic structure. Determination of oblateness of the earth from observations of an artificial earth satellite in 1960 occupied V. F. Proskurin, Yu. V. Batrakov, I. D. Zhongolovich and others at the institute. To find the oblateness of the earth it is necessary to have good elements of the satellite and especially motion of the node Ω'. Meanwhile accuracy of visual observations is small, while errors in determination of instants have an especially strong effect. To decrease the influence of these errors on determination of elements D. K. Kulikov and Yu. V. Batrakov in 1960 developed a method which permits excluding not only error in fixation of moments of time during the determination of certain elements, but also unaccounted for influences of atmospheric drag.

Let us stop briefly on question connected with calculation of the ephemeris of artificial satellites. This problem consists in calculation of the position of a satellite on the celestial sphere with respect to an observer and in determination of conditions of visibility of the satellite. For calculation of the ephemeris on 1960 the institue composed special tables (I. D. Zhongolovich and A. M. Amelin). For mass calculations of the ephemeris a special method was simultaneously developed which considers the peculiarities and possibilities of high speed computers (A. S. Sochilin). Finally, M. S. Volkov, using the Poincaré method, in the cycle of works from 1962-1963 constructed a periodic solution in the problem of rotation of a satellite in the field of gravitation of a spherical or compressed planet.

Zone of Minor Planets (Asteroids)

According to data on 1 January 1965, the minor planets numbered 1660. Of them around 97% has an average distance from the sun within limits from 2.2 to 3.6 astronomical units. Thus, the majority of minor planets is located between orbits of Mars and Jupiter. The

structure of the asteroid zone is very complex. The distribution curve of the number of minor planets depending upon diurnal motion has somewhat sharply expressed maxima and minima, which are in a specific relation to the diurnal motion of Jupiter.

The mathematical theory explaining the existence of "hatches" in the zone of minor planets is very complicated and is still not completely developed. New results in this question were obtained by Yu. V. Batrakov in 1958.

Study of the motion of the minor planets presents a difficult problem in celestial mechanics. Analytic methods developed for the major planets usually become unfit for the minor planets. This is explained by the fact that small parameters by which decompositions are conducted cease to be small for the minor planets. In particular, the proximity of Jupiter makes the ratio of the major semiaxes of Jupiter and the minor planets closely to unity.

Furthermore, for many small influences, especially for those recently discovered, the number of known observations is so small that the question of creating an analytic theory of motion for them at least is premature. Therefore it is necessary to use methods of numberical integration of equations of motion employing contemporary computers. This whole complex of questions has been the center of attention of the Institute of Theoretical Astronomy from the very beginning of its existence.

According to a proposal of B. V. Numerov in 1924 for calculation of perturbed coordinates of the minor planets for the first time direct integration of equations of motion in rectangular coordinates was used. The Cowell method was modified by Numerov by introducing "special" coordinates, so that integration was very fast without successive approximations (Numerov method).

The works of D. K. Kulikov (1960) developed Cowell's method in its original form, but with the use of high-speed computers.

Simultaneously with numberical methods the institute developed approximate analytic methods of the calculation of perturbations. Wilson's tables for calculation of perturbations of planets of the Minerval group and Bolin's table for planets of the Vesta type. The periodic orbits of A. Poincaré and K. Shwartzschild were used in 1951 by G. A. Chebotarev to study the motion of the small planets, including planets of the Hilda group, for which classical methods of celestial mechanics turned out to be completely unsuitable.

V. F. Proskurin in 1953 developed an analytic theory of motion for Ceres accurate to terms of the first order relative to the perturbing masses.

In 1958 N. G. Polozova made it possible to use electronic computers to create a strict analytic theory of motion for the minor planets. If the eccentricity of a planet is small, then after several hours it is possible to find perturbations of the first order by Hill's method.

These theoretical works made possible wide participation of Soviet astronomers in the International Epehmeris Service of the Minor Planets. By the second world war the Institute of Theoretical Astronomy occupied second place in the world in works done in the field of motion of the minor planets. First place belonged to the Berlin Calculating Institute.

The second world war distrubed international organization in the Service of the Minor Planets. In 1945 publication of the ephemeris of the minor planets by the Berlin Calculating Institute ceased. At the All-Union Astrometric Conference held in Moscow October, 1945 the necessity of renewing calculation of the ephemeris of the minor planets was recognized, and the Institute of Theoretical Astronomy offered to start this work. Thus, the institute took on a problem which had been handled for half a century by the Berlin Calculating Institute.

Starting from 1947 and up to the present time the institute has

published yearly the "Ephemeris of the Minor Planets," which are the only publications of this kind in the world. The use of numerical methods in the presence of contemporary computer technology permits calculating the overwhelming majority of ephemerides of the minor planets taking into account perturbations. Thereby the institute was able to achieve essential progress in solving the problems of the ephemeris service of the minor planets. These problems were solved by a large collective of colleagues under the general leadership of N. S. Samoylova-Yakhontova and S. G. Makover.

The use of high-speed electronic computers led to the solution of certain other problems connected with the study of motion of the minor planets. Thus, F. B. Khanina in one year definitized orbit of 150 minor planets.

In 1932 the Soviet astronomers B. V. Numerov, M. F. Subbotin and N. I. Dneprovskiy advanced the possibility of orientation of fundamental catalogs using observations of the minor planets. However, research in this region was for a long time delayed. Subsequently by proposal of N. S. Samoylova-Yakhontova in 1945 several Soviet and foreign observatories organized systematic observations of ten chosen minor planets, and the treatment of observations and construction of the numberical theories of motion was taken on by the Institute of Theoretical Astronomy.

Dynamics of Cometary Orbits

Comets are unconditionally the most mysterious class of objects in the solar system. By contemporary ideas they form an extensive cloud (Oort cloud) on the boundaries of the solar system. The orbits of the comets in this cloud have major semiaxes — from 50,000 to 150,000 astronomical units — and all possible eccentricities and slopes to the plane of the ecliptic. Under the influence of the stars they experience considerable perturbations. In 1964 G. A. Chebotarev showed that apparently it is more correct to consider as the disturbing body not individual stars randomly passing near the

solar system, but the nucleus of the galaxy as a constantly acting factor which causes the evolution of orbits in the Oort cloud and thereby determines the dynamic boundaries of the solar system. If the perichelio distance of the comet becomes small, then the comet area the perihelion turns out to be in the region of motion of large planets. Perturbations from large planets can move the comet into a hyperbolic orbit, after which the comet leaves the solar system forever.

In other cases planetary perturbations decrease the major semiaxis and eccentricity of the orbit. After that the comet passes into an elliptic orbit and forever remains near the sun, having a comparatively small period of inversion. Interesting results on questions of the evolution of cometary orbits are obtained in works of the Riga theoretician K. A. Shteyns for 1953-1965.

Here there is no possibility of mentioning all the numerous works on application of methods of celestial mechanics for calculation of the final orbits of nonperiodic and long-period comets, and also in the study of the evolution of orbits of short-period comets. Among the most outstanding Soviet theoreticians working in this area it is necessary to note the Kazan astronomer A. D. Dubyago (1903-1959), studying from 1924 to 1959 the motions of the periodic comets Brooks, Daniel and Shayn-Shal'dek. He also proposed in 1942 original theories of the causes of secular acceleration, observed for the majority of periodic comets. According to this theory secular acceleration is caused by the reaction forces appearing as a result of the ejection of particles of matter from the nucleus of a comet as it passes near the sun.

Let us stop in somewhat greater detail on the work of S. G. Makover on the theory of movement of Encke's comet. This comet, discovered in 1818, was the first object whose movement could not be explained completely by Newton's law of universal gravitation. The period of inversion of the comet, freed from the influence of planetary perturbations, turned out to be not constant but systematically decreasing from turn to turn. To coordinate all observations Encke proposed the hypothesis that the comet moves in a resisting

medium. However, this hypothesis turned out to be a failure, just as a series of other attempts to explain the anomaly of movement of the comet. Even the Pulkovo astronomer O. A. Baklund, investigating the movement of this comet according to observations from 1871 to 1916, arrived at the conclusion that the acceleration of its movement (and accordingly reduction of its period of inversion) occurs near a perihelion. S. G. Makover in 1955 was able to show that the movement of Encke's comet can be represented very exactly by the same system of elements, if to the gravitational perturbations from large planets an additional acceleration is added at every passage of the comet through the perihelion in agreement with the hypothesis of A. D. Dubyago. Thus, the puzzle of Encke's comet, inexplicable for almost 150 years, can be considered as completely explained. Another important result of the work of S. G. Makover was a new determination in 1956 of the mass of Mercury according to the perturbations which this planet causes in the movement of Encke's comet.

The value of the mass of Mercury with respect to the mass of the sun (m = 1:6,280,000) obtained by Makover agrees completely with other determinations. This result serves as an important additonal proof that the contemporary theory of movement of Encke's comet completely reflects its real movement.

In connection with the question of the origin of comets, the study of the movement of comets whose eccentricities of orbits are close to one is of real value. In order to determine the initial orbit of such a comet, we should with the help of numerical integration trace the movement of the comet through a series of preceding years, far enough back to be sure that perturbation up to this moment were insignificant. The question about the character of the future orbit of the comet after it goes beyond the limits of the orbit of Pluto is solved similarly. A very effective way to calculate the initial and future orbits was shown by Makover, who proposed to use as the independent variable for integration, not time, but the true anomaly of the comet. In 1954 I. V. Galibin applied this method to all as yet uninvestigated long-period comets with sufficiently precise elements. According to

the results (1958-1964) all these comets had in the past elliptic orbits, i.e., belonged to the solar system. Regarding, however, future orbits, then approximately half of all comets as a result of planetary perturbations are ejected from the solar system on hyperbolic orbits.

The movement of comets in the sphere of action of Jupiter is of great interest. An exact method of investigation of cometary perturbations in this case was developed in 1961 by Ye. I. Kazimirchak-Polonska. She showed in particular that an insignificant change of the mass of Jupiter leads to essential deviations in the presentation of observations of a comet after its approach to the planet.

This fact opens new possibilities for determining the mass of Jupiter.

Astronomical Ephemerides

Calculation of the various kinds of astronomical ephemerides composes an important division of celestial mechanics. Basic ephemerides, ensuring all possible astronomical and geodesic work, and also naval and air navigation, and at present even the navigation of spaceships, will be issued in the form of astronomical yearbooks.

Prior to the Great October Socialist Revolution astronomical work in Russia (both scientific and industrial) was carried out with the help of annuals published abroad. Therefore the Institute of Theoretical Astronomy from the very beginning of its organization was faced with the basic problem of developing astronomical ephemerides.

As a result of the enormous work done by the institute, at present we have not only a first-class "astronomical yearbook," providing for complete astronomical, geodesic and hydrographic work, but also special ephemerides — the "Naval Astronomical Yearbook" and "Aviation Astronomical Yearbook" — adapted for the most effective service of naval and air navigation.

In the Soviet Union during the period of 1917-1965 B. V. Numerov (1891-1943), M. D. Rozhnov (1892-1945), N. I. Idel'son (1884-1951), N. S. Yakhontov, M. F. Subbotin (1893-1966), D. V. Zagrebin and D. K. Kulikov (1912-1964) played prominent roles in the work on astronomical yearbooks. The problem of creating special astronomical ephemerides (naval and aviation astronomical yearbooks) was successfully solved under the leadership of I. D. Zhongolovich.

An important division in the astronomical yearbooks is the tables of solar and lunar eclipses. Classical theories of eclipses were augmented in works of A. A. Mikhaylov 1919-1945. Under his leadership over many years precomputations were made of solar eclipses visible in the USSR.

From 1911 the composition of national astronomical yearbooks has been conducted in terms of an exchange of materials between corresponding institutes of different countries. During the years of the Great Patriotic War, when international scientific communications were interrupted, the Institute of Theoretical Astronomy ensured completely independent calculation of all divisions of the "astronomical yearbook of the USSR." The use from 1939 of computers (at the initiative of M. D. Rozhnov and I. N. Yanzhul) solved this problem in a comparatively short time. The 1941 "astronomical yearbook," composed under the leadership of N. I. Idel'son, was the first issue of the "great" astronomical yearbook, completely calculated in the USSR and standing on the level of the best foreign annuals. A distinctive feature of the Soviet "astronomical yearbook" from the very beginning of its publication was the tendency to ensure completely astronomical and geodesic work in the territory of the USSR by the visible places of stars used in geodesic practice. In this respect, as and in certain others the Soviet "astronomical yearbook" is the most complete among national annuals and therefore is widely used abroad in socialist and certain capitalistic countries.

Constant development of science and technology, increase of accuracy of astronomical calculations, and in recent years the solution to problems of mastering outer space require continuous improvement

of astronomical ephemeric, reconsideration of methods of their calculation, increase in accuracy, introduction of new numerical values for astronomical constants.

Therefore the "astronomical yearbook of the USSR" constantly is improved in order to remain on a high theoretical level in accordance with requirements of science and technology. Thus, for example, in 1960 there was an important reform of the "astronomical yearbook of the USSR," connected with increasing the accuracy of ephemerides.

In 1964 the XIIth Congress of the International Astronomical Union resolved to introduce into astronomical yearbooks, starting with 1968, new numerical values for the system of astronomical constants. The transition to a new system of constants presents a complex problem which is being solved with the close collaboration of the Institute of Theoretical Astronomy (USSR), the British Bureau of the Ephemeris (England), the Bureau of the American Ephemeris (United States) and the Bureau des Longitudes (France).

Moscow School of Celestial Mechanics and Its Work[1]

1. At Moscow State University imeni M. V. Lomonosov the chair of celestial mechanics was organized relatively recently, namely in 1938, i.e., already more than 20 years after the Great October Socialist Revolution. However, collective of the chair, a fully defined scientific group older than the chair itself, and the basic directions of the work of the chair appeared much earlier than its organization. Therefore to correctly understand the role and value of the Moscow school of celestial mechanics it is necessary to examine the history of the group of astronomer-theoreticians in Moscow and the basic stages of development of its scientific activity.

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[1]This section was written by G. N. Duboshin.

It is necessary to note first of all that in the first years of Soviet power (1917-1920) in Moscow there wasn't any group of scientists which would be somehow united by general interests in the region of celestial mechanics. However, there already existed an Astronomical Society, in the useful enlightening work of which participated many persons interested in different regions of astronomy. Among them were also amateur theoreticians whose interests were inclined to the calculations and algebraic computations of celestial mechanics. Furthermore, various questions of celestial mechanics were examined sometimes in sessions of the Moscow Mathematical Society and even, although very rarely, at sessions of the Moscow Society of Naturalists and Physicians.

Individual (not connected organizationally) amateurs in celestial mechanics — S. A. Kazakov (1873-1936), I. F. Polak (1881-1954), A. A. Mikhaylov, K. L. Bayev (1881-1953), G. N. Sveshnikov and certain others — usually were very overloaded by pedagogic and scientific and organizational work and could not allot much time to their personally interesting, but, it would seem, distant from stormy practical life, scientific work in the region of celestial mechanics.

At Moscow University there was at that time only one general chair of astronomy, which carried out the preparation of specialists in astronomy. In 1918 one of the leading professors of this chair was Sergey Alekseyevich Kazakov, who conducted in those years the following courses: 1) determination and correction of orbits of the minor planets and comets, 2) celestial mechanics, 3) theoretical astronomy, 4) spherical astronomy and 5) computer technology and interpolation. These courses were attended by all students specializing in astronomy (they were quite few!), and even certain students whose specialty was mathematics or theoretical mechanics. The cause of the great polularity of lectures by S. A. Kazakov at Moscow University was the unusual pedagogic skill of lecturer, thanks to which the most difficult questions of celestial mechanics were clearly and distinctly illuminated.

The author of this sections was a pupil of S. A. Kazakov, had the luck to hear his lectures and very well remembers the calm, unhurried manner of the professor, and gentle humor, at times bringing to life the discussion and exact formulations of theorems and rules and excellent chalk drawings on the board.

Besides the lectures of Kazakov, student astronomers interested in "theory" listened also to lectures of A. A. Mikhaylov, who taught higher geodesy, theory of eclipses, theory of the figure of the earth and certain other, not so "theoretical" courses. Finally, theoretical courses also include the course of S. V. Orlov (1880-1958) on the theory of cometary forms, in which both fundamental results of F. A. Bredikhin and the investigations of Orlov (a well-known Soviet specialist on comets) were expounded.

2. At the beginning ot the 1920's in Moscow appeared two large astronomical institutes. In November, 1922, in the physics and mathematics department of Moscow University was organized the Association of Scientific Research Institutes, which included 11 institutes, in particular the Astronomical and Geodesic Scientific Research Institute (AGNII). The director was S. N. Blazhko. The composition of this institute included only one specialist in celestial mechanics, S. A. Kazakov, who because he was overburdened by organizational and pedagogic work, could not create a brilliant school of celestial mechanics and directed no scientific activity in this region.

In March, 1921, from the organizational committee and astrophysical conference which it held on the construction of the Main Russian Astrophysical Observatory was formed the Russian Astrophysical Institute, renamed in May, 1923, the State Astrophysical Institute (GAFI). In the organization of the new institute its cadres were comprised mainly of young people, who enthusiastically took over scientific work not only in the region of astrophysics, but also in other regions of astronomy. Their number counted lovers of theory (K. L. Bayev, B. M. Shchigolev, N. D. Moiseyev, K. F. Ogorodnikov,

N. N. Pariyskiy and others), who, however, did not form a spearate theoretical group, but were scattered through other, already existing sections of the institute (cometary astronomy, stellar statistics).

The department of theory in GAFI was organized only at the end of 1925 under the name "Department of Theoretical Astrophysics." This group became the nucleus from which was formed later the Chair of Celestial Mechanics of Moscow State University. The first session of the department of Tehoretical Astrophysics, taking place 12 November 1925, can be considered the beginning of activity of the Moscow group of theoreticians.

Very quickly, at the very beginning of 1926, in the section Professor of Mathematics of Moscow University V. V. Stepanov was made senior scientific colleague. Then to the department of theory came B. M. Shchigolev and N. D. Moiseyev, and the department continued gradually to be supplemented by students and graduate students, finishing Moscow State University.

The scientific direction of the department followed an extensive plan of investigations of mathematical character, concerning the properties of motions of real celestial objects (stars, planets, satellites, clusters, etc.), under the action either of practically observed space forces, or not observed hypothetical, but possible forces.

From the very beginning of activity in the Moscow group of theoreticians appeared a tendency to conduct qualitative investigations of planetary motion, i.e., tendency to study such general properties of motion as appearance and form of trajectory of a moving body, finite properties of motion, etc. However, already under the influence of V. V. Stepanov (specialist-mathematician) the group began development of analytic theories of motion for the purpose of obtaining in the form of matematical formulas a solution to those differential equations which must inevitably be considered in any problem of celestial mechanics. These tendencies of colleagues of the department, soon renamed "Department of Theory" GAFI, are explained

on the one hand by the personal tastes of colleagues, and on the other by the influence of the leaders.

During the first few years of its existence the Department of Theory GAFI was able to conduct a series of investigations, printed mainly in "Astronomical Journal," on several important problems in the theory of planetary motion. These works were dedicated to the theory of internal structure of stars, examined as the totality of a multitude of particles moving under the action of cosmic forces, problems of the dynamics of star clusters and investigation of the general properties of motion of particles in a medium, simultaneously gravitational and resisting, study of the form of branches of spiral nebulae and other problems of stellar dynamics. In spite of the apparent separation of these works and their formal disconnectedness, they nonetheless were in the general framework of the single plan which was mentioned above.

At the end of 1928 the director of the Department of Theory was V. V. Stepanov, who played in the creation of the Moscow school of celestial mechanics a very important role. V. V. Stepanov was a sensitive and strict critic of all works of mathematical character, especially from the point of purity and validity of mathematical proofs. Stepanov was the author of original ideas in mathematics and mechanics, always in the virgin territory of mathematical literature.

Under Stepanov, whose closest assistant was soon N. D. Moiseyev, the plan of scientific work of the department gradually changed (mainly to an increase of exactitude and strictness of formulations of problems, but not essentially). The basic direction was foundation and mathematical development of existing cosmogonic theories. This direction, obtaining the name "dynamic cosmogony," remained the leading one in the work of the Department of Theory for several years and led to interesting and useful results, in many respects covering, supplementing and definitizing a series of results of foreign scientists working in that same region.

3. In 1931 the State Astrophysical Institute, which up to this time was an independent establishment and absolutely did not depend on Moscow University, was combined with the Scientific Research Astronomical and Geodesic Institute of Moscow State University. Colleagues of both institutes composed the cadres of this new institute, which was included in the system of Moscow State University under the name of the Joint State Astronomical Institute imeni P. K. Shternberg (abbreveated OGAISh, and soon simply GAISh). In connection with this the Department of Theory began to be called the "Theoretical group" OGAISh (June, 1932 renamed the "Section of Cosmogony and Celestial Mechanics" GAISh).

After the merging of GAFI and AGNII the director of the theoretical group, and then of the Section of Cosmogony and Celestial Mechanics was the oldest astronomer-theoretician of Moscow State University, S. A. Kazakov. In a supplement of a study of problems of cosmogonic character he directed the attention of theoreticians of the section to problems of strictly celestial mechanics, which at the time was occupied by the study of motions chiefly of bodies of the solar system (major and minor planets, comets, satellites, meteors). It is especially necessary to note extensive work of the section in the region of a general theory of stability of motion, created by A. M. Lyapunov, and its concrete applications to celestial mechanics.

In this direction extraordinarily fruitful and active was the work of N. D. Moiseyev, who during the 1930's and 1940's introduced to the Lyapunov theory of stability many new original ideas, promoting development of this theory and its practical application. Examining the multitude of particles forming at an initial moment a compact cloud, i.e., being at very close distances from each other, and solving the problem about stability (or instability) of a certain "leading" motion in the field of force, we find it possible to judge about the further fate of such a cloud, namely about its preservation in compact form (in case of stability of leading motion) or about its scattering in time (in case of instability). For dynamic cosmogony of the 1930's-1940's such problems and their strict solution played a great role. On the other hand application of methods of the theory

of stability to celestial mechanics permitted constructing exact analytic theories of motion of celestial body in the form of an infinite series, convergent absolutely and evenly in a certain interval of time. Furthermore, for celestial mechanics it turned out to be possible to use A. M. Lyapunov's theory of periodic solutions, based on the theory of stability, more general than the well-known theory of Poincaré, and including the latter as a special case. Finally, a certain further generalization of the theory of Lyapunov was developed, namely the theory of stability during constant operational perturbations (G. N. Duboshin, end of 1930's).

Besides the theory of stability, the section used other methods to qualitatively study planetary motions. The basic work in this direction was the work of N. D. Moiseyev and his pupils in the 1930's and 1940's (N. F. Reyn, G. K. Badalyan, T. V. Vadop'yanov and others) on the development of a method of contact characteristics. This method originates with works of Poincaré and Adamar (second half of the XIXth to the beginning of the XXth century), dedicated to general and geometric characteristics of integral curves of systems of differential equations, determining motion in the dynamic problem. As the experience of subsequent work showed, use of this method can give many valuable indications with respect to character of motion, form of trajectories and, so forth.

A series of problems in celestial mechanics was examined in work dedicated to use of the method of so-called contact characteristics. Here we find the work of N. D. Moiseyev on the study of motions in special cases of the three-body problem (bounded circular and elliptical three-body problem, Hill's problem, Fatu's problem), work of N. F. Reyn on study of periodic orbits and motions in the gravitational medium, work on application of averaged Gaussian-type (and more general) schemes and also many others. These investigations included G. K. Badalyan's presently very timely work on the properties of motion in the problem of two stationary centers and the work of Kondurarya on the theory of translational-rotational motion of celestial bodies, which was the first link of an extensive cycle of work of V. T. Kondurarya himself and many other scientists later.

In 1936 N. D. Moiseyev (1902-1955) was named director of the section. He was an unusually energetic and able-bodied (in spite of severe illness) person, possessing much learing in the physical and mathematical disciplines in general, and astronomy in particular. He was the true founder of the Moscow school of the Moscow School of Celestial Mechanics and directed the work of the theoretical group for almost 20 years up to his own premature death in December, 1955.

4. The end of the 1930's saw the beginning of a new period in the histor y of the GAISh theoretical group, marked by organization of the chair of celestial mechanics. During this time the mechanics and mathematics department of MGU was joined by the Division of Astronomy made up of six chairs of astronomy in addition to the GAISh departments. Thanks to the energy, persistence and efforts of N. D. Moiseyev among these chairs of astronomy the chair of celestial mechanics was also organized and headed by Moiseyev. During the Great Patriotic War the chair, not interrupting its scientific work of celestial mechanics, was also occupied with the development of certain special needs for the front.

In the summer of 1941 GAISh was almost completely evacuated to Sverdlovsk. At Moscow B. M. Shchigolev and G. N. Duboshin, remained to teach at Moscow State University until the end of October, 1941, and then after a break again went back to their pedagogic work in February, 1942.

In 1944 GAISh returned to Moscow, and the chair of celestial mechanics renewed its work. But by this time the Section of Celestial Mechanics and Cosmogony had actually ceased existence and the theoretical group of GAISh continued work only in the composition of the chair. The chair went completely to subjects of celestial mechanics and concentrated its attention on qualitative investigations in the region of the organic three-body problem, the theory of perturbed motion and the construction of analytic theories of motion of natural satellites of certain major planets and also asteroids.

Nikolay Dmitriyevich
Moiseyev

1902-1955.

N. D. Moiseyev set as his own target the study of general properties of trajectories in problems of celestial mechanics on the basis of using differential equations of motion and certain known integrals and constructed in the 1940's-1950's an absolutely new theory in celestial mechanics on the satisfactoriness of osculating elements of perturbed Kepler motion (elliptic). N. D. Moiseyev and his pupils conducted a qualitative study of a series of concrete problems of celestial mechanics, i.e., problems about the motion of fully concrete bodies of the solar system, and also the question about practical application of qualitative results to certain bodies was posed and solved.

In particular, it was shown that the "lost" minor planets had unsatisfactory elements according to criteria of N. D. Moiseyev.

A later large cycle of N. D. Moiseyev's work in celestial mechanics was on the study of secular and long-period perturbations in motions of natural celestial bodies, mainly the minor planets. Starting in 1945 N. D. Moiseyev investigated in detail earlier proposed averaged diagrams (Gauss, French scientist Delaunay and others) and constructed a series of new averaged diagrams, of practical use in his own work and in work of his colleagues (K. A. Shteyns, M. S. Yarov-Yarovoya, the young Hungarian scientist Arpad Pal and others).

The so-called interpolation-averaged diagrams, first created by Moiseyev, should be especially noted. Their basic idea can be briefly formulated. From results of observations of celestial bodies are derived approximate empirical integrals. These integrals are used to average the force function, after which differential equations of motion are integrated by quadratures. Quadratures deliver approximate formulas, making it possible to calculate and to judge about the general properties of motion. Thus a theory is constructed which then can be definitized by comparison with observations. The development of this method (which occupied Moiseyev until his death) was shared by other colleagues of the chair (G. N. Duboshin, A. A. Orlov, M. P. Kosachevskiy), who used it in their own works on constructing an analytic theory of motion of the satellites of Saturn, Uranus and Mars. In these works, however, in contrast to Moiseyev's work, the averaged equations were integrated somewhat differently, for example, by using methods of A. M. Lyapunov, developed by him for use in problems about stability of motion and adapted by GAISh for the actual calculation of series satisfying averaged equations and representing the motion of satellites.

At the same time in 1945-1955 another branch of the same direction was developed, namely a theory of motion of a celestial body was constructed using the averaging not of the actual force function, as was done in already mentioned investigations, but its derivatives, i.e., right sides of differential equations of motion (B. M. Shchigolev). Furthermore, at the chair work continued on the

theory of stability of motion both from the point of view of developing supplements to the actual theory and from the side of its applications.

During several postwar years many colleagues of the chair were occupied with development of applications of the theory of A. M. Lyapunov and its changes in form (N. D. Moiseyev) not only to problems of celestial mechanics, but also to purely technical problems. Soon after the war the chair renewed and intensified its work on the preparation for publication of original and translated educational and training-auxiliary literature.

This period in the life of the chair was completed in 1955 by the merging of the chairs of celestial mechanics and gravimetry into a single chair, named the "Chair of Celestial Mechanics and Gravimetry," for which the subjects of scientific work considerably expanded.

After the death of N. D. Moiseyev, G. N. Duboshin in 1956 became the director of the Chair of Celestial Mechanics and Gravimetry.

At the end of 1957, after the Soviet Union launched the first artificial earth satellite in the world, the Chair of Celestial Mechanics and Gravimetry began gradually to pass to new subjects, namely the theoretical study of motions of artificial celestial bodies. The new region of science which appeared – theory of motion of artificial celestial bodies, or, as in now frequently called "astrodynamics" – promoted wide interest toward problems of celestial mechanics in the most diverse circles of specialists.

The basic problems of astrodynamics at present are: translational motion of any kind and type of artificial earth satellites (and also artificial satellites of the moon, Mars, Venus); rotation of artificial satellites; space flights from the earth to the moon, Venus or Mars (or at least to a region near these bodies); rotation of spaceships during interplanetary flights; flights to other regions of outer space, for example to regions far from the ecliptic plane and a multitude of other problems.

The motion of an artificial celestial body which already is in orbit subsequently can occur exclusively under the action of natural (not depending on the will of man) forces - attractions, replusions, resistances of medium, radiation pressure, etc. In this case the problem of the motion of such a body in principle does not differ from the problem of motion of a natural celestial body and can be distinguished from the latter only by initial (or final) conditions. But if during the flight of an artificial celestial body additional forces begin to act, depending on the will of man and controlled by him, then a fundamentally new problem appears about the motion of such bodies which requires new methods for solution. The Chair of Celestial Mechanics pursued a solution of problems of the first kind, and according to traditions and interests of colleagues of the chair - their analytic solution.

It is known that in practice problems about the motion of artificial celestial bodies are decided at present for the most part by numerical integration of differential equations of motion on high-speed computers. However, the construction of an analytic theory of motion presents independent interest; furthermore, it facilitates also direct numerical operations and provides many possibilities for qualtative investigations.

First of all in the period from 1955 to 1965 colleagues of the chair pursued the development of an analytic theory motion of artificial earth satellites under the action of the attraction of a nonspherical earth and the perturbing influences of the moon and sun, and also an analytic theory of the rotation of a satellite around its center of masses. Along the way other problems were examined, for example the general problem about translational-rotational m tion of a solid, calculation of conditions for interplanetary flights, etc. The theory of motion of an artifical satellite in the gravitational field of the earth, developed at first by Ye. P. Aksenov, Ye. A. Grebenikov and V. G. Demin, and then only by Ye. P. Aksenov, is considered especially promising. This theory takes as the initial orbit not the Kepler ellipse, but a trajectory closer to reality in which the influence of the oblateness of the earth already is

considered and which is the trajectory of a certain specially selected problem of two fixed centers.

Another variant of the problem about motion of a satellite in the gravitational field of the earth is the problem examined by A. A. Orlov (GAISh), which uses the very convenient method of Deloné, and makes it possible to find rather simply perturbation from separate harmonics in the decomposition of the earth's potential.

At present work has been successfully begun on an analytic theory of interplanetary trajectories (G. N. Duboshin, M. S. Yarov-Yarovay). This work is based on the possibility of building a convenient series representing motion of the ship in powers of a certain regularizing (in the sense of Sundman, Levy-Chivit) variable.

It is obvious that in the very near future the solution of the tremendous problem for man's conquest of outer space will also lead to new outstanding successes in the solution of problems of celestial mechanics.

THE PLANETS AND THEIR SATELLITES

It is difficult to evaluate physical investigations of the planets of the solar system and their satellites. After all, among celestial bodies planets are the closest in nature to our earth, and a study of the many sides of the physics of the earth is impossible without a comparison with other planets. Planets are the only bodies on which organic life can appear and develop. This is why besides purely astronomical problems, planetary study meets problems solved by geophysics, geochemistry, geology, biology, meteorology and others. Futhermore, the planets and their satellites, especially the earth's own moon, are the nearest celestial bodies to the earth, and three of them - the moon, Venus and Mars - already are inside the sphere of attainability of contemporary space rockets. Man's entrance into the Cosmos made a visit to the moon and planets by astronauts a reality, which still more increases the role and value of investigation now. However, half a century ago, in the second decade of the XXth Century, the position was different. At that time the possibility of space flights was not even discussed seriously in scientific circles; the pioneer works of Tsiolkovsky were not wide-spread, and in other countries no similar works were being carried out. In astronomy theoretical astrophysics and the physics of the stars and nebulas developed rapidly, and the problem of stellar astronomy and cosmology was intensively attacked.

The nature of the planets and satellites at that time was given comparatively little attention. Individual researchers, depending

upon their interests, from time to time carried out works on the physics of the planets, having sometimes a very important value. An example of such work in particular are the determination by A. A. Belopol'skiy (1895-1909) of the periods of rotation of the planets by the spectral method and the first photographs of Mars with light filters, obtained in 1909 by G. A. Tikhov.

In the first years of Soviet power, our country conducted mainly visual observations of the planets. Starting with 1918 regular observations of Mars (and then also Venus) were conducted in Kharkov by N. P. Barabashov, and in Leningrad by A. V. Markov. The same period embraces the first investigations of the nature of Jupiter by V. G. Fesenkov (1917) and his work on selenology (1917-1922).

The predominance of visual observations of the planets in those years was connected with the almost total absence of large instruments and good astrophysical instruments (spectrographs, photometers and others). The 30-inch refractor at Pulkovo after 1909 was used mainly for spectroscopy of the stars and sun, and the 15-inch refractor was used for astrometric observations. The 40-inch reflector of the Simeiz Observatory, obtained in 1925, also was used to study the spectra of the stars. Observations of the planet were conducted in our country in that period with 5 to 10-inch telescopes. However, even in the 1920's we began to develop photometric and polarimetric studies of the planets and the moon. Application of the method of photographic photometry permitted N. P. Barabashov (1922) and A. V. Markov (1924) to establish and theoretically interpret the fact that any detail on the moon attains maximum brightness in a full moon.

By the beginning of the 1930's the Soviet photometric school had been basically formed, and its members included V. G. Fesenkov, N. P. Barabashov, V. V. Sharonov (1901-1964), N. N. Sytinskaya and young astronomers working at two basic centers of planetary investigations: the Kharkov Astronomical Observatory under N. P. Barabashov and the Astronomical Observatory of Leningrad University under V. V. Sharonov.

Improvement of methods and improvement of instrument possibilities (in particular, the use of the 30-inch Pulkovo telescope and the normal astrograph of the Tashkent Observatory for photographing planets) demanded the development of theoretical research in the absorption and scattering of light in the atmosphere of the planets and the reflection of light from the surfaces of planets. Concerning planets with rarefied atmosphere (as of Mars) this was done in works of V. G. Fesenkov (1944), N. N. Sytinskaya (1944-1948) and N. P. Barabashov (1946). Theoretical research on light scattering in turbid and dense gaseous environments was carried out by V. A. Ambartsumyan (1941-1942), who developed a general theory of light scattering in a turbid medium, and V. V. Sobolev (1944-1949), who developed methods of approximation of the solution to this problem by applying it to atmospheres of a planet similar to Venus. Subsequently results of these investigations were put in monographs (V. A. Ambartsumyan and others, 1952; V. V. Sobolev, 1956). Almost simultaneously (1944-1950) a general theory of scattering in optically solid media was developed in the United States by S. Chandrasekar, whose monograph in 1953 was translated into Russian.

Vsevolod Vasil'yevich
Sharonov

1901-1964

The direction of the work of both branches of the Soviet photometric school - Kharkov and Leningrad - somewhat differed.

At Kharkov N. P. Barabashov and his colleagues (B. Ye. Semeykin, A. T. Chekirda, I. K. Koval', V. I. Yezerskiy and others) paid primary attention to the accumulation and treatment of observations. They obtained (using light filters) numerous observations of the moon, Venus, Mars, Jupiter and Saturn, by which the values of visible albedo (reflectance) and the character of his change considering a change of angles of incidence and reflection of solar rays were determined for these planets, the indicatrix of reflection for lunar and Martian types and the indicatrix of scattering for the atmosphere of Venus were worked out, photometric properties of atmospheres of Jupiter and Saturn were studied. The works of the colleagues of the Kharkov Observatory as a rule contain detailed tables (or graphs) of photometric parameters of the planets for every date of observations, which permits any researcher to use them for checking his own theory or for comparison with his own observations. Many results of the work of Kharkov astronomers are summarized in monographs of N. P. Barabashov (1952, 1957), in his surveys (1932, 1937, 1948, 1960) and in collections (1959).

The Leningrad school, headed by V. V. Sharonov and N. N. Sytinskaya, posed as a basic problem the more precise determination of basic photometric parameters characterizing the general reflective properties of different surfaces and the reflectance of the planets as a whole, the development of a method of photometric investigations and carrying out laboratory experiments. At the same time V. V. Sharonov and his pupils (N. S. Orlova, L. N. Radlova, I. A. Parshin and others) conducted numerous observations, using methods of both visual and photographic photometry. The methodical investigations of Leningrad photometrists are in a monograph by N. N. Sytinskaya (1948), in surveys and monographs of V. V. Sharonov (1940, 1954, 1958, 1965). As a result of these investigations besides the long-known ideas of geometric, spheric and true albedo (Lambert's albedo) in planetary photometry appeared such new ideas as the brightness coefficient, visible albedo (brightness factor), illustrative albedo,

luminosity. If for an orthotropic surface many of these formally different values are equal to each other (spherical, illustrative and true albedo, and also luminosity), then for an nonorthotropic surface they can essentially differ, which was insufficiently considered in former works.

In order to show the value of the work of Soviet photometrists in the study of planets prior to the 1950's, it is sufficient to give one example. In the summary of determinations of atmospheric pressure on Mars, composed by the French scientist G. Vaucouleurs (1951, Russian translation 1956), Soviet scientists are credited with half of all the determinations (5 of 10). These works pertain to 1933-1944. At the end of the 1940's Soviet astronomers, lagging now their foreign colleagues (mainly due to the absence of corresponding equipment), started to use electrophotometric methods (A. V. Markov) and polarimetry (Yu. N. Lipskiy) in the study of the moon. However, we conducted individual studies in visual polarimetry of the moon even earlier, in the 1920's.

It happened that after the classic work of A. A. Belopol'skiy in our country no spectral investigations of the planets were conducted for a long time. The cause of this was furthermore the absence of large instruments, forcing the use of indirect (colorimetric) methods instead of direct (spectrophotometric).

The restoration of observatories, destroyed during the Patriotic War, including the Pulkovo and Simeiz, and the installation of new instruments in place of those destroyed demanded considerable time, efforts and resources. Only in the 1950's did Soviet planetary astronomy obtain the necessary instrument base, which continues to be expanded and to improve.

But even before this, starting from 1947, in Soviet planetary astronomy appeared a new area. G. A. Tikhov (moving during the war from Pulkovo to Alma Ata) began active work on a hypothesis of the vegetable nature of the "seas" of Mars and used the services of specialist biologists, with whose participation the Department of

Astrobotany of the Academy of Sciences of the Kazakh Soviet Socialist Republic was organized. The department worked basically on a study of the spectral reflective properties of plants growing in different climatic conditions, and comparison of them with corresponding properties of the "seas" of Mars. In this work besides astronomers (G. A. Tikhov, N. I. Kucherov, A. K. Suslov and others) botanists also participated (A. P. Kutyreva, V. S. Tikhomirov, K. I. Kozlov and others).

Gavriil Adrianovich
Tikhov

1875-1960

Work done by the school of G. A. Tikhov obtained wide fame. Vegetable life on Mars was the center of hot discussions (at scientific conferences and in print). However, after the death of G. A. Tikhov (1960) the Department of Astrobotany ceased to exist and purposeful investigations in this region almost ceased.

Approximately from the beginning of the 1950's a new stage in the development of planetary study in our country began. Even at the end of the 1940's a Commission on the Physics of the Planets was formed in the Astrocouncil, and was directed a long time by N. P. Barabashov. Now is is headed by D. Ya. Martynov. In May, 1949, at Kharkov the first conference on the physics of the planets was conducted at which Soviet leaders in planetary studies organized the first wide exchange of opinions on basic scientific problems. At the same time the question of constructing special planetary telescopes was discussed.

The new stage was characterized first by an expansion of the instrument base of the Soviet planet astronomy; secondly, organization of planetary studies in a number of new observatories and institutes, where there had been no earlier study, and attracting a great number of young astronomers; thirdly, wide use of new various methods of investigation: spectroscopy (including infrared), radio astronomy (including radar), polarimetry and others. Finally, in the study of the moon starting from 1959 robot space stations have been used.

At present Soviet leaders in planetary studies have such first-class tools as the 122-centimeter reflector and 260-centimeter Shayn reflector at the Crimean Astrophysical Observatory, the 125-centimeter reflector of Southern Station GAISh in the Crimea, 70-centimeter telescopes AZT-8 of the Astrophysical Institute of the Academy of Sciences of the Kazakh Soviet Socialist Republic in Alma Ata and AZT-2 of the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian Soviet Socialist Republic in Goloseyevo, similar telescopes of the Astronomical Observatory of Kharkov University, AGISh and Abastumani Observatory.

New centers for planetary studies appeared: at Pulkovo (A. V. Markov, N. A. Kozyrev, N. I. Kucherov and others) Alma Ata (V. G. Teyfel'), Kiev (I. K. Koval' and others), Abastumani (V. P. Dzhapiashvili). Planetary studies were embraced by the Departments of Radio Astronomy of the Pulkovo Observatory, Physics Institute im. P. N. Lebedev of the Academy of Sciences USSR, Gor'kiy Radio

Physics Institute, Institute of Radio Engineering and Electronics and others.

Let us now turn to a short survey of achievements of Soviet Astronomers in the study of separate planets and their moons.

The Moon

The moon has always been for astronomers a convenient object for observation and study. In the Soviet Union moon studies took several basic directions.

1. Investigation of photometric properties of the lunar surface. As was already mentioned above, this is one of the earliest subjects of moon study in the USSR. Even in the 1920's N. P. Barabashov and A. V. Markov showed that any object on the moon attains maximum brightness in full moon, and not at the time of greatest height of the sun above the horizon. This "Barabashov-Markov effect" was explained by the pitting of the lunar surface and the presence of much irregular detritus. The surface of the lunar "seas" and "mainlands" is porous and rough.

Numerous photometric observations of the lunar surface made in 1948-1952 by A. T. Chekirda and V. A. Yzerskiy (Fedores), gave a detailed picture of the change of brightness of different formations with phase.

A series of studies was dedicated to clarification of the color of lunar details. Starting with 1950 N. P. Barabashov obtained a series of color photographs of the moon showing the presence of various color shades on the lunar surface. On the other hand, colorimetric observations of V. V. Sharonov and L. N. Radlovaya indicated minute values of color contrasts. As spectrophotometric investigations of V. G. Teyfel' showed, in most cases color contrasts on the moon do not exceed 8%, but in particular cases attain 15-20%, while these places coincide with the most colored regions on photographs of N. P. Barabashov.

Many researchers strived to compare albedo, color indices, scattering factors, curves of spectral reflectance of the lunar surface and different terrestrial rocks, and also meteorites (V. V. Sharonov, N. P. Barabashov, A. T. Chekirda, N. S. Orlova and others). Full similiarity with even one form of rocks was not obtained. The surface of the moon turned out to be darker than all terrestrial rocks and redder than meteorites. Nearer than others in photometric and polarization properties are volcanic slag, volcanic ashes; further we have tuff, lava, obsidian and certain basic rocks (basalt, diabase, gabbro).

2. Nature of external cover of the moon. This question was discussed repeatedly here and abroad from the widest points of view. Basic initial data for its solution were, first, photometric investigations, which we spoke of above, and, secondly, determination of the change of temperature of the lunar surface during the time of a full phase cycle (lunation) and during lunar eclipses in the infrared and radio-frequency band.

Already in 1957 N. N. Sytinskaya advanced her "meteor-slag hypothesis," according to which the lunar surface is covered everywhere by a crust of porous foam-like material, appearing from the substance of the lunar bedrock under the influence of the high temperature accompanying the explosions of meteorites falling on the surface of the moon. The dark color of the external cover Sytinskaya explains by the separation of iron oxides from the silicates which are in the composition of lunar rocks.

A competing hypothesis was the "dust hypothesis" of the English astronomer T. Gold, according to which the external cover of the moon consists of a thick layer of dust. The basic argument in its favor was the low values of thermal conduction of the lunar surface, which were determined indirectly from radio observations of the change of temperature of different sections of the moon during lunation and lunar eclipses.

A series of observations of the moon on wavelengths of a very

wide range (from millimeter to decimeter) was conducted by V. S. Troitskiy and his colleagues at the Gor'kiy Radio Physics Institute starting from 1958. Analysis of these observations brought V. S. Troitskiy to the conclusion that the external cover of the moon resembles not dust, but a friable porous material with density $\rho \sim 0.5$ g/cm^3. At a depth of 1-2 m temperature fluctuations connected with lunations and lunar eclipses completely cease and with further depth the temperature increases. Extrapolating the temperature gradient, referred to an external layer of 20 m, Troitskiy expressed the opinion that at depth 50 km temperature reaches 1000°.

Subsequent observations using an "artificial moon" – a four-meter black disk with rated temperature – confirmed the appraisal of density of the external layer and showed that its thermal conduction, which is 30-40 times less than for terrestrial rocks, nevertheless is 40-50 times more than for a layer of thin dust. This substance, conditionally called "moonite," should be porous, externally resembling pumice, and in radiating properties close to volcanic rocks. Thus, the studies of V. S. Troitskiy's group confirmed the "meteor-slag" hypothesis of N. N. Sytinskaya. Still more graphic verification came from photographs of the lunar panorama, obtained by the Soviet station "Luna-9" in February, 1966. They clearly show the porous, slag-like structure of the lunar surface. The same showed up in photographs from "Luna-13" (December, 1966).

An interesting fact is the luminescence of the lunar surface, first revealed in 1946 by the Czech scientist F. Link from observations of lunar eclipses and confirmed by N. A. Kozyrev (1956) from the narrowing of profiles and the increase of residual intensity of H and K lines in the spectrum of certain craters.

3. Origin of lunar forms. The origin of basic forms of the lunar surface – craters, "seas" and light rays – has been the subject of a great many work of Soviet astronomers. As it is known, even in the last century science has witnessed the struggle between supporters of the theories of endogenous (volcanic) and exogenous (meteoritic) origin of lunar craters. One of the objections to the meteoritic

hypothesis was for a long time the round form of the craters, whereas under the oblique impacts of meteorites elliptical shapes should have occurred.

In 1937 K. P. Stanyukovich showed that at the time of impact of a meteorite against the surface of a planet a central-symmetric explosion occurs, and therefore the shape of the crater does not depend on the angle of incidence. In 1947 K. P. Stanyukovich and V. V. Fedynskiy gave an approximate theory of crater formation as a result of meteoritic impacts, and through 1950-1960 Stanyukovich developed a more general theory, using experimental data from powerful ground explosions. The application of this theory to lunar, and also to terrestrial meteoritic craters was the subject of a work by K. P. Stanyukovich and V. A. Bronshten in 1960-1965. However, works of Stanyukovich carried mainly a phenomenological character. Another approach - from the cosmogonic point of view - can be found in works of B. Yu. Levin (1955-1962).

Already in 1949 the American selenologist R. Baldwin in his book "The Face of the Moon" gave a developed account of the meteoritic hypothesis in its new form: taking into account explosive phenomena and extending the shock-explosive mechanism to the formation not only of craters but also of round "seas." "Seas," according to Baldwin, were formed as a result of lava effusions after the impacts of comparatively large bodies - planetisimals. He showed that the "diameter-depth" relationship for hallows from bombs and shells, meteoritic and lunar craters obeys one law

The change from the prevailing point of view of the formation of the moon by separation from the earth to the theory of accumulation of the moon from hard planetisimals permitted a giving a new, cosmogonic foundation to the meteoritic hypothesis of the origin of lunar relief. It was done in works of B. Yu. Levin in the USSR and B. Yuri, G. Kuiper in the United States. All these researchers consider that the bombardment of the moon occurred as a result of a loss on it (and on the earth) of the remainders of a primary cluster of bodies, from which were formed the earth and the moon.

But where Yuri (1960) examines the capture of a "ready" moon by the earth, Levin (1962) assumes accumulation of the moon from circumterrestrial cluster of bodies with a "delay" of 200-300 million years as compared to the earth. The history of the formation of the moon is examined in a number of works by Ye. L. Ruskol (1960-1962), and its further thermal evolution is found in works of Levin and S. Mayevaya (1960-1965).

Explanation of different forms of lunar relief within the bounds of the meteoritic hypothesis was the subject of a great number of works both here and abroad. The Soviet amateur astronomers P. F. Sabaneyev and A. M. Benevolenskiy carried out (1953-1959) a series of successful experiments on substantiating this hypothesis, recreating the formation of many characteristic shapes of lunar craters (rays, central ridges, partitions, secondary craters and others) by dropping solids and lumps of powder on a powdery layer of substance.

No less popular was the endogenous (volcano-tectonic) hypothesis. The year 1949 saw publication of a thorough monograph by geologist A. V. Khabakov, which gave a detailed analysis of structural peculiarities of lunar relief, estimated the relative age of different formations and developed a unified picture of the evolution of the lunar surface. According to Khabakov, the periods of formation of craters and "seas" alternated. His classification of 1960 counts seven such periods: the most ancient, Hipparchus or Doalt [Translator's Note: exact spelling for the Russian Доалтайский (Doaltsyskiy) not found] (formation of the ancient walled-plains), Altay (early stage of formation of circular "seas"), ptolemaic (formation of majority of craters), ocean (formation of the most recent craters and "seas"), Copernican and contemporary.

Simultaneously with works of A. V. Khabakov similar investigations were being conducted by geologists in other countries: K. Byulov in the German Democratic Republic (1955-1965), J. E. Spurr in the United States (1944-1950), G. Fielder in England (1955) and others from 1962-1965 in the USSR this problem attracted the attention of many geologists (Yu. A. Khodak, V. B. Neyman and others), who, approaching

the study of lunar relief from geological positions, try to substantiate the volcano-tectonic scheme of the origin of lunar craters.

It is obvious that on the moon occur volcanic phenomena. Besides the well-known observations of the emission of gases from the central ridges of the crater Alphonsus by N. A. Kozyrev and V. I. Yezerskiy in 1958 and a similar phenomenon in the crater Aristarchus in 1959, this is also indicated by such formations as lunar domes.

Independently of any any manifestations of volcanism on the moon, meteorites fell and continue to fall. Photographs obtained by the American Ranger stations in 1964-1965 showed the presence of a continuous sequence of craters from 250 km to 1 m in size, with a preservation of structural similarity. This result was an important arugument in favor of the meteoritic hypothesis of their origin. A defect in the volcanic hypothesis was always the absence any mathematically developed mechanism of the formation of craters.

4. Use of robot space stations. Photographs of the reverse side of the moon, obtained by the Luna 3 station 7 October 1959 and the Zond 3 station 20 July 1965, introduced an essential contribution to study of the nature of our satellite. Interpretation of photographs obtained by the Luna 3 and composition of an atlas of the reverse side of the moon were assigned to three observatories: GAISh, Pulkovo and Kharkov. As a result of this treatment the "Atlas of the Reverse Side of the Moon" edited by A. A. Mikhaylov, N. P. Barabashov and Yu. N. Lipskiy was published (1960).

Consideration of photographs obtained by the Zond 3 gave even more interesting results. These photographs had a much higher resolving power; on them one may see nearly 3500 craters and other objects. Essentially new on these photographs was the detection of extended crater chains up to 1.5 thousand km long, which many times exceeds the extent of similar chains on the visible side of the moon. Photographs were treated at the State Astronomical Institute im. P. K. Shternberg, the Astronomical Observatory KhGU and at the Pulkovo Observatory. On the reverse side of the moon are few "seas," but then there are extensive sea-like depressions 200-300 km in

diameter, called thalassoids. Thalassoids are bounded by a ridge (usually not solid), and in the central part is a flat round slab. Such formations are also on the visible side of the moon.

By proposal of Soviet Scientists 172 formations on the reverse side of the moon were named in honor of the most prominent scientists, and inventors and designers of jet engines from 19 countries. An honorary place among them is occupied by Russian and Soviet scientists.

The first photographs of the panorama of the lunar surface, obtained by the Soviet station Luna 9, making a soft landing on the moon in the Sea of Storms 3 February 1966, were of outstanding value. The station transmitted to earth three full circle panoramas at various heights of the sun above the horizon (7, 14, and 27°) and part of a fourth panorama (at 42°). Resolving power of these photographs attains 1-2 mm. Photographs from the Luna 9 permitted a detailed study of the microstructure of the lunar surface and made possible a new confirmation of the meteor-slag hypothesis of N. N. Sytinskaya. The moon's surface where the station landed was pitted by shallow craters from several meters to 10 cm and less in diameter. On the surfaces evident trails of erosion are seen, connected apparently with micrometeorite impacts and the action of the "solar wind." The loose layer of ground on the moon, as showed photographs from Luna 9, Luna 13 and the American Surveyor 1 (landed on the moon 2 June 1966), is very thin (not thicker than several centimeters).

The launching of the first Soviet artificial satellites of the moon – Luna 10 (put into selenocentric orbit 3 April 1966), Luna 11 (28 August 1966) and Luna 12 (25 October 1966) – permitted obtaining many valuable scientific data about circumlunar outer space, and Luna 12 obtained and transmitted new close photographs of the moon (up to 100 km).

The first measurements of the magnetic pole of the moon and the intensity of radiation near it were made by the Luna 2 in 1959. Magnetic measurements conducted at up to 50 km from the surface of the moon did not show signs of a magnetic field, which, if it exists,

does not exceed 0.1-0.2% of the earth's. Radiation measurements at up to 1000 km from the surface did not reveal a growth of intensity of radiation within limits of 10% of the space background. This signified that the moon for practical purposes has no radiation belts.

The sensitivity of magnetometer on the Luna 10 was 15 times higher than for the luna 2. Its measurements showed that magnetic field strength in circumlunar space fluctuates within limits from 17 to 35 gammas and changes little in different points of orbit. In the environment of the moon was revealed an increased intensity of low energy, particle fluxes, in particular of electrons. Furthermore, it turned out that the volume density of micrometeorites near the moon is higher than in surrounding interplanetary space.

The gamma-ray spectormeter on the Luna 10 permitted a study of gamma radiation emitted by radioactive isotopes (uranium, thorium and potassium-40) in the composition of lunar rock, and also radiation appearing during their bombardment by comsic rays – the latter required around 90% lunar radiation. Analysis of gamma-ray spectra of the moon showed that the amount of radioactive elements in lunar rock corresponds to the amount in terrestrial rock of basic (basaltic) or ultrabasic (dunite) composition. Conversely, rock with a high content of radioactive elements (for example, granite) did not occur in the studied regions of the moon.

5. Studies of the figure of the moon. Such studies were made over many years by A. A. Yakovkin at Kiev and now are continued by A. A. Gorynaya and I. V. Gavrilov (Main Astronomical Observatory of the Academy of Sciences of the Ukrainian SSR).

In 1934 A. A. Yakovkin proposed a model of the structure of the moon with concentric distribution of density, in which noncoincidence of the center of the figure with the center of masses depends only on the relief. This model explained a number of observed phenomena (libration effect, stretchability of the disk in the polar direction and others). In 1950-1955 this model was successfully used to treat observations of the figure of the moon for 21 years. A more complex model was proposed in 1960 by A. A. Yakovkin and A. A. Goryaya.

The figure of the moon and its physical liberationwas studied also by I. V. Bel'kovich, A. A. Nefed'yev, Sh. T. Khabibullin (Astronomical Observatory im. V. P. Engelhardt) and Kh. I. Potter (Main Astronomical Observatory, Academy of Sciences USSR). Nefed'yev composed detailed maps of boundary relief of the moon (1958).

Venus

Methods used in studies of Venus in the USSR, as in the whole world, experienced a breakthrough in the middle 1950's. Therefore they can be conditionally divided into "classical" and "contemporary." "Classical" methods include visual observations, visual and photographic photometry, colorimetry and polarimetry, and also spectroscopic observations in the visible part of the spectrum. "Contemporary" methods can also embrace spectroscopy of the far infrared region of the spectrum, radio astronomical methods, radar, observation from ballons and robot space stations.

1. Visual observations. Even at the beginning of the 1920's at the Kharkov Observatory N. P. Barabashov began a study of Venus by the visual method. However, numerous visual observations of this planet, conducted with the most diverse instruments by many observers in various countries, gave very modest results. From time to time on the disk of Venus light spots were observed, while some of them presumably connected the poles of the planet. According to published data of the observations of such spots for 1912-1950 I. T. Zotkin and A. N. Chigorin in 1953 attempted to determine the slope and direction of the axis of rotation of Venus, obtaining coordinates of the north pole $\alpha = 8°$, $\delta = +62°$ and 39° slope of equator to plane of orbit. This position of the pole is 26° from that obtained by Goldstein using the radar method ($\alpha = 299°$, $\delta = +78°$, accurate to ±15°).

2. Photometric investigations of Venus have been intensively carried out in our country. In particular, integral colorimetry (determination of the index of color and color excess — index of yellowness of Venus) was conducted in 1948-1952 by N. P. Barabashov,

A. T. Chekirda and V. I. Yezerskiy according to spectrophotometric observations, and also by comparison of the visual observations of Müller and Danjon with photographic observations of King, where a certain change of the index of yellowness with phase was obtained. In 1948-1956 V. V. Sharonov conducted several series of visual comparisons of the color of Venus and the sun, and in 1954 I. A. Parshin determined the index of yellowness according to surface photometry.

Surface photometry of the disk of Venus was conducted visually by N. P. Barabashov in 1919-1923 and photographically by N. P. Barabashov and B. Ye. Semeykin in 1932 using light filters. This last work began an extensive series of observations, conducted in subsequent years by V. V. Sharonov (1940, 1961), I. A. Parshin (1948-1954), V. I. Yezerskiy (1957) and I. K. Koval' (1958). Moreover in the works of N. P. Barabashov, V. I. Yezerskiy, I. A. Parshin and I. K. Koval' it was found that the maximum brightness of intensity on the equator corresponds to the condition of equality of the angles of incidence and reflection ($i = \varepsilon$), i.e., a quasi-specular reflection of solar rays occurs. Reflecting elements could be, in the opinion of the authors of these works, ice crystals in the clouds of Venus or even water spaces on its surface (this conclusion was made prior to radio astronomical measurements of the temperature of the surface of Venus). At the same time V. V. Sharonov did not confirm the result, finding that at the point of maximum brightness $i > \varepsilon$. In 1964 N. P. Barabashov and I. L. Belkin at the Kharkov Astronomical Observatory treated spectrograms of the large dark spot on Venus. Spectral distribution in the dark spot on Venus, obtained for the first time, showed that similar spots are noticeable not only in the ultraviolet region of the spectrum, as was considered earlier, but also in the visual region. In the presence of such spots, which, in general, appear quite often, the distribution of brightness on the disk of Venus changes strongly. This apparently explains why V. V. Sharonov could not find the mirror effect found by N. P. Barabashov. The distinction of the drop in brightness in the ultraviolet region of the spectrum noticed by various observers is also the result of the appearance and disappearance of these spots.

It is necessary to note the first work on absolute photometry of the disk of Venus, carried out by I. A. Parshin (1954), absolute photometry of the planet in ultraviolet and infrared rays, conducted by I. K. Koval' (1958), and also the comparison of the indices of light scattering in the atmosphere of Venus and in the layer of water droplets, conducted by V. V. Sobolev (1944) on the basis of his approximate theory of light scattering in dense atmosphere and the phase curve of Venus, obtained by Müller.

In 1950 an analogous investigation was made by N. P. Barabashov and V. I. Yezerskiy, using the Danjon phase curve. Good qualitative similarity of indicatrixes for the atmosphere of Venus and for drops of water was obtained.

The numerous photometric investigations of Venus by Soviet astronomers are most fully illustrated in a large work by V. I. Yezerskiy (1957) and in a monograph of V. V. Sharonov (1965).

3. Spectral investigations of Venus were begun in our country rather recently – in 1953 by N. A. Kozyrev. After the pioneer work of A. A. Belopol'skiy (1900-1911), having as its purpose the determination of the period of rotation of Venus according to the slope of lines in its spectrum and not giving any defined results, only spectrophotometric observations for a study of the color of Venus (see above) were made.

In 1953 N. A. Kozyrev with the help of the 122 cm reflector of the Crimean Astrophysical Observatory of the Academy of Sciences USSR first studied the spectrum of the dark part of the disk of Venus and revealed a series of emission bands, of which two (λ3914 and λ4278 Å) he ascribed to ionized and neutral molecular nitrogen, and the others remained unidentified. For the bright crescent N. A. Kozyrev obtained a general lowering of the reflectivity of Venus by the ultraviolet end of the spectrum. The luminous intensity of the dark side of Venus is 50 times greater than the brightness of the earth's night sky and can be explained by aurore polaris.

This work of N. A. Kozyrev provided the impetus to similar studies in other countries, first in the United States. It is true that the American astronomers (Richardson, Kiess, Owen) did not confirm the presence of emission bands, and Newkirk observed only some of them, confirming, however, the estimate of the brightness of the night sky of Venus obtained by Kozyrev. Kozyrev could not observe emission bands in 1956-1961, and then his investigations produced much discussion, promoting further work in this region.[1]

Searches for absorption bands of oxygen in the atmosphere of Venus, conducted by V. K. Prokof'ev and N. N. Petrova in 1961-1964 and leading to a positive result, are of great interest also. It is true that recently in the United States doubt of the authenticity of this result has been expressed, and new investigations are required for a final solution.

Work on the investigation of the far infrared spectrum of Venus was undertaken in our country only from 1961, with a fifteen-year delay as compared to the first work in this region by Kuiper (1946). Nonetheless the work of V. I. Moroz in the Crimean Observatory and at the Southern Station GAISh led to very interesting results. Six new absorption bands were discovered in the infrared region of the spectrum (1.1-2.5 μm), of which one belongs to CO_2 and two to the CO_2 molecule with heavy carbon C^{13}. It was possible to estimate the C^{12}/C^{13} ratio, equal approximately to 100, which is close to the analogous ratio for the earth's atmosphere. Also found was a smooth lowering of the albedo of Venus with wavelength on a section 1.1-2.5 μm.

For the ultraviolet region of the spectrum I. N. Glushneva (GAISh) in 1963 did not obtain a sharp fall of albedo with decrease of wavelength as earlier revealed by N. A. Kozyrev. However T. A. Polozhentsev (1966) showed that the distribution of brightness over the spectrum (in its ultraviolet region) changes from day to day and

[1]In 1964 N. A. Kozyrev obtained the emission spectrum of a flare on the dark hemisphere of Venus. In the opinion of V. K. Prokof'ev lines of elemental nitrogen were present.

the results of N. A. Kozyrev and I. N. Glushneva do not contradict each other.

4. Radio astronomical observations and their interpretation. The first observations of the radio emission of Venus were carried out in the United States in 1956, and in our country in 1959 at the Serpukhov Station of the Physics Institute im. P. N. Lebedev of the Academy of Sciences USSR (A. D. Kuz'min, A. Ye. Salomonovich). Subsequently Soviet radio astronomers conducted numerous series of observations of the radio brightness of Venus on wavelengths from 4 mm to 9.6 cm, studying its change with phase. In 1962 the Pulkovo radio astronomers (D. V. Korol'kov, Yu. N. Pariyskiy, G. M. Timofeyeva, S. E. Khaykin) first studied the distribution of radio brightness across the disk of the planet, revealing a drop by the edges of the disk and very small excess of radio diameter over the visible. This favored the idea that Venus has no radiation belts, and the source of radio emission is its surface. Both results were confirmed during the flight of the American station Mariner 2.

The sharp distinction of the radio temperatures of Venus on millimeter and microwaves, revealed by both Soviet and foreign researchers, required theoretical interpretation, as also, and the actual value of temperatures (350-410°K on λ0.4-1.18 cm and 500-690°K on λ1.35-21.0 cm). Furthermore, in constructing theoretical models of the atmosphere of Venus it was necessary to consider data from infrared radiometry ($T \sim 235$°K) and determination of the rotational temperature across the CO_2 bands (285°K).

Soviet astronomers and geophysicists participated in discussion of both alternative hypotheses about the structure of the atmosphere of Venus: greenhouse effect and ionospheric hypothesis (a third – eolosphere hypothesis of Epik – did not find support among Soviet astronomers). The basic idea of the ionospheric hypothesis was expressed in 1961 by A. D. Kuz'min and A. Ye. Salomonovich independently of D. Jones, who in the West is considered to be the author of this hypothesis. A thorough investigation of the ionospheric model was made in 1961-1964 by A. D. Danilov and S. P. Yatsenko,

who tried to coordinate it with the results of not only radio astronomical, but also radar observations on 10-70 cm wavelengths. They proposed a model of a "porous" ionosphere for Venus with a lower hot layer ($T_e \sim 1500°K$) and an upper cold ($T_e \sim 600°K$), where the coefficient of porosity is close to 0.5. A close model offered in 1963 by A. D. Kuz'min. However, investigation of polarization of the thermal radio emission of Venus, carried out in 1965 by A. D. Kuz'min jointly with B. Clark at the observatory in Owens Valley (the United States), showed that the source of radio emission from Venus is its surface, and not the atmosphere. This work received many responses in Soviet and foreign literature. Of great value for checking both models were radar observations of Venus in which waves of different length twice pass through the atmosphere of the planet, experiencing in it absorption. Such observations were conducted starting from 1961 at the Institute of Radio Engineering and Electronics of the Academy of Sciences USSR under V. A. Kotel'nikov (see the section "Radio Astronomy").

Another result of radar observations of Venus was the independent establishment of its reverse rotation and estimate of the period (230-250 days) in good agreement with the foreign determinations (242-248 days).

A theoretical analysis of the structure of the atmosphere of Venus, founded on the use of radio oaservations (within the bounds of the greenhouse hypothesis), was made in 1965-1966 by G. M. Strelkov, A. D. Kuz'min and others. The used observations of a rare phenomenon — covering of Regulus (star α Leonis) by Venus 7 July 1959. Although this phenomenon was not observed in the USSR, treatment of the published brightness curve of Regulus permitted D. Ya. Martynov and M. M. Pospergelis to obtain values of height of the homogeneous atmosphere and hypothetical temperature above the level of the cloud layer, and also to express a series of considerations about the distribution of temperature by height. Martynov calculated by these observations the radius of Venus, confirming the value of Auwers (6100 km).

Mars

In investigations of Mars in the USSR it is possible to outline three basic directions:

1) "classical" methods of investigation analogous to those for Venus (visual observations, photographic photometry and colorimetry);

2) astrobotanical investigations, having the special problem of confirming the hypothesis about the presence of vegetation on Mars;

3) investigations of the spectrum of Mars in the far infrared region.

1. Visual observations of Mars were conducted by N. P. Barabashov starting from 1920 in almost every opposition. During the years of great and near-great oppositions, the observations of Mars involved many astronomers and also amateurs. Results of these observations were usually maps of the surface of the planet and descriptions of separate parts. Observations of Mars in the period of the last favorable opposition in 1956, when a series of unusual phenomena in its atmosphere and on its surface was noted, are of great interest: the appearance of powerful dust clouds, light spots in the regions of Argyre and Noachis, sharp turbidity of southern hemisphere and others. Detailed descriptions of these phenomena were published by N. P. Barabashov, V. A. Bronshten and V. V. Sharonov. Under the editorship of N. P. Barabashov the "Atlas of the Figures of Mars" (1961) and the collection "Results of Observations of Mars During the Favorable Opposition of 1956 in the USSR" (1959), were published.

Thorough synoptic observations of cloud formations in the atmosphere of Mars were conducted for many years by N. P. Barabashov. The melting rate of the southern polar cap in 1956 was determined by micrometric observations of V. A. Bronshten.

2. Photographic photometry and colorimetry. These types of

observations began to be used systematically for Mars in our country starting with 1933 (N. P. Barabashov and A. T. Chekirda), although already in 1909 G. A. Tikhov for the first time photographed Mars through light filters, allowing him to discover the three well-known "Tikhov effects" (change of visibility of light and dark spots and polar caps, and also contrasts between time in different rays).

Colorimetric and spectrophotometric observations of the surface and atmosphere of Mars were conducted by N. P. Barabashov, B. Ye. Semeykin, A. T. Chekirda, I. K. Koval' in Kharkov, by N. N. Sytinskaya and V. V. Sharonov in Tashkent and Pulkovo, G. A. Tikhov and his colleagues at Alma Ata. The theory applied to the treatment of these materials was developed in 1944 by V. G. Fesenkov and in 1944-1948 by N. N. Sytinskaya.

As a result of these observations curves of spectral reflectivity of different Martian formations were obtained (polar caps, continents, "seas"), curves of the drop in brightness at the edge of the disk (for comparison with laws of diffuse reflection), determination of "sea-mainland" and "mainland-polar cap" contrasts in different rays, and also determination of density of the Martian atmosphere.

Above, the place which Soviet photometric determinations of the density of Martian atmosphere held among other methods prior to 1956 was already mentioned. Abroad these methods were hardly used, although polarimetric and spectroscopic investigations were better developed there.

In exactly the same way determinations of spectral reflectivity of Martian formations carried out by Soviet photometrists was long the only information about the possible nature of these formations. A valuable aid in comparison of these determinations with characteristics of the earth's surface is the work of Ye. L. Krinov "Spectral Reflectivity of Natural Formations" (1947). The experimental investigations of photometric and color properties of different terrestrial rocks, conducted at the Astronomical Observatory of Leningrad State University under V. V. Sharonov were also of great value.

Basic results of the work of Soviet photometrists with respect to the nature of the surface of Mars lead to the following. The continents of Mars are covered by a finely crushed substance and reflect by Lambert law. Their color and albedo correspond to limonite ($Fe_2O_3 \cdot nH_2O$). Polar caps are close in reflecting properties to river ice.[1] Regarding "seas," they do not reflect by Lamber law and are more rought than the continents (I. K. Koval', 1957; V. A. Bronshten, 1962).

3. Astrobotanical investigations. As was already said above, these investigations were conducted mainly by G. A. Tikhov and his colleagues and consisted in the comparison of spectral reflective properties of the "seas" Mars and terrestrial plants. One of the most important results obtained by the school of G. A. Tikhov was the detection on earth of plants not possessing Wood effect, i.e., increased reflectivity of infrared rays. The majority of terrestrial plants manifest this property so strongly that in infrared rays they seem white. The "seas" of Mars on the contrary do not possess this property. The school of G. A. Tikhov showed that the absence or softening of the Wood effect is a criterion of the adaptation of certain plants to severe conditions of climate. Certain specialists in biology set up experiments on growing plants at low pressures and temperatures (S. M. Tokmachev, L. M. Lozina-Lozinskiy), the results of which indirectly confirmed the hypothesis of G. A. Tikhov about the presence of vegetation on Mars.

Whereas G. A. Tikhov allowed the possibility of existence on Mars of even the highest plants, his opponents V. G. Fesenkov and O. V. Troitskaya (biologist) came forward in 1952-1954 with a series of objections, leading to the full negation of the possibility of life on Mars. Besides the purely scientific questions, discussions touched also certain philosophical problems.

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[1]However, N. P. Barabashov (1952) found that polar caps are red. This, in general, does not contradict their ice nature, if one were to consider that frequent dust storms on Mars can cover them with a layer of reddish dust.

An interesting attempt to predict properties of assumed Martian vegetation on the basis of certain physical conditions on the surface of the planet is the work of K. A. Lyubarskiy "Synopses on Astrobiology" (1962). In it a conclusion is made about the predominant role in the pigmetation of Martian plants of carotenoids over chlorophylls, and also a series of considerations is made on their most "profitable" (from the point of view of Martian conditions) structure. This work gives an objective criticism of works of the school of G. A. Tikhov and views of V. G. Fesenkov.

4. Investigations of the infrared spectrum of Mars. These investigations were started in 1963 by V. I. Moroz at the Southern Station GAISh with the help of a sulfur-lead photoresistor fastened to a 125-cm reflector. During the investigation of the infrared spectrum of Mars in the region of 1.1-4.1 μm 12 CO_2 bands were found, of which 7 earlier were not observed; the presence of "Sinton bands" on λλ3.43, 3.53, 3.59 and 3.69 μm has been confirmed, attributed to organic compounds (the second band was not noticed by Sinton), and also the presence of absorption bands of ice in the spectrum of the polar cap. With the help of another receiving system V. F. Yesipov and V. I. Moroz studied the spectrum of Mars in the region of 0.6-1.0 μm. The albedo of Mars drops with wavelength, and the whole picture of its change in the interval of wavelengths 0.4-4.0 μm satisfactorily agrees with the spectra of reflection of limonites.

From the CO_2 band Moroz made a new estimate of the pressure of the atmosphere of Mars at the surface: around 20 mbar, which agrees well with recent estimates of American astronomers, but is 3-4 times less than estimates founded on photometric and polarimetric observations. As Sytinskaya indicated, this divergence is connected with dust in the Martian atmosphere: scattering created by particles of aerosol, registered earlier as gas components of the atmosphere. The American probe Mariner 4 gave still smaller values: 4-7 mbar. It is possible that the smallest dust particles suspended in the atmosphere of Mars introduce a contribution to the Rayleigh component of scattered light, so that it is doubtful whether the true pressure of the atmosphere of Mars exceeds 10 mbar.

5. Certain theoretical works. In 1957 A. I. Lebedinskiy examined the hydrologic cycle on Mars. Proceeding from the condition of radiation equilibrium in the atmosphere of the planet, where the basic heat sink is carbon dioxide, Lebedinskiy constructed a model of the atmosphere, in which temperature decreases with height, tending to a limit value of 110°K. A close model was constructed in the United States by Goody. As A. I. Lebedinskiy showed, steam forming as a result of melting of the polar cap, should rapidly disappear, and the transfer of moisture be carried out in the form of small hard ice crystals or snowflakes. Subsequently the problem of the hydrologic cycle on Mars was developed by A. I. Lebedinskiy and G. I. Salov.

V. D. Davydov expressed a hypothesis about the existence on Mars of a layer of permafrost and about the formation of "channels" due to the cracking of the surface in places of where there are ice outcroppings. However, it is doubtful whether this hypothesis will be able to be checked by obtaining more detailed investigations with the help of space rockets and robot space stations.

Original views on properties of Martian atmosphere were expressed by N. A. Kozyrev (1957), who considered it capable of considerable selective absorption and explained by this the many color properties of the surface of Mars. The ideas of Kozyrev were met with criticism and did not obtain the support of the majority of astronomers.

Mercury

Investigations of the spectrum of Mercury were conducted almost simultaneously (in 1963) by V. I. Moroz and N. A. Kozyrev. V. I. Moroz, studying the infrared spectrum of the planet in region $\lambda\lambda$ 1.0-3.9 μm with the help of the same setup as for the spectrum of Mars, found on $\lambda\lambda$ 1.576-1.606 μm CO_2 bands, estimated the pressure at the surface as 2 mbar and constructed a model of the atmosphere of Mercury. N. A. Kozyrev, studying contours of lines of hydrogen (H_γ and H_δ) in the spectra of Mercury and the sun, revealed in the

spectrum of the planet an asymmetry of these lines, which it explained by the presence of hydrogen in its atmosphere, introduced by solar corpuscular streams. This result still requires confirmation, even more so because American observations with a higher dispersion in the spectrum gave cause for an absolutely different interpretation of this phenomenon.

Jupiter

Visual observations of Jupiter were conducted for many years by Soviet astronomers – specialists and amateurs. Results of these observations were maps of the visible surface of the planet, tables and graphs of latitudes and the widths of bands, regularly published in "Bulletin VAGO." Dependence of width and intensity of bands on solar activity was studied by V. V. Fedynskiy (1927, 1933), A. M. Bakharev (1948) and B. M. Rubashev (1951), but their results are contradictory. A study of variability of width of the two main (tropical) bands of Jupiter for 65 years, carried out by V. A. Bronshten, A. N. Sedyakina and Z. S. Strel'tsovaya (1967), showed no connection with solar activity and the presence of fluctuations of band with period of 3-4 years.

Considerable changes in the appearance of Jupiter in 1962, accompanied by a merging of both tropical bands into one, were described by S. K. Vsekhsvyatskiy. Numerous photometric observations of Jupiter in different rays were conducted from 1932-1939 by N. P. Barabashov and in 1938 by V. V. Sharonov. These observations are well represented by the theory of V. A. Ambartsumyan of light scattering in a solid medium. Fast changes on Jupiter are explained, according to N. P. Barabashov, by the evaporation of droplets of methane and small crystals of ammonia or the reverse processes. A purely gas layer above the cloud level should be optically thin.

In recent years (1958-1965) various spectrophotometric investigations of Jupiter were conducted by V. G. Teyfel (Institute of Astrophysics of the Academy of Sciences of the Kazakh SSR). Study of the distribution of intensity over the disk along the equator

in the band of methane 6190 Å did not show any distinctions with distribution in a continuous spectrum. The search for latitudinal distinctions of the equivalent width of this band did not confirm the conclusions of Hess (1953) about the existance of such distinctions. Optical thickness of the gas layer in the center of the band was estimated by Teyfel' at 0.05, and in the continuous spectrum – at 1-2 orders less, which coincides with the conclusion of N. P. Barabashov. Teyfel' detected also certain color distinctions between zones and strong absorption in the ultraviolet region of the spectrum of the planet. An investigation of the spectrum of the Red Spot showed that the upper edge of the spot does not differ in height from the upper border of the cloud layer, which contradicts the hypothesis of Wildt about the Red Spot as a solid body floating in the atmosphere of Jupiter. Rather, it is a gas formation, containing aerosols and having infinite optical thickness. Ultraviolet absorption in the Red Spot is stronger than in other places of the disk.

Different theoretical models of the internal structure of Jupiter were developed by V. G. Fesenkov (1924), V. G. Fesenkov and A. G. Masevich (1951) and N. A. Kozyrev (1951). According to the model of V. G. Fesenkov and A. G. Masevich, Jupiter has a hard nucleus consisting of hydrogen and heavy elements (density 7-11 g/cm^3), an intermediate layer of "packed" atomic hydrogen (density 0.8-2.8) and an external layer of molecular hydrogen (density 0-0.4). On the edges of the layers density changes by a jump.

Kozyrev expressed an idea about a high temperature – up to 200,000° – in the center of Jupiter, generated by radioactive decay.

There is great interest in observation of the radio emission of Jupiter, which constitutes a combination of three forms: thermal, nonthermal (synchrotron) and sporadic radio emission. These observations were conducted starting from 1963 at the Pulkovo Observatory (Yu. N. Pariyskiy and others) on 3 and 6.5-cm wavelengths, at the Scientific research Radio Physics Institute of Gor'kiy State University (V. S. Troitskiy and others) on 70-cm wavelengths and at the Institute of Radio Engineering and Electronics AN USSR

O. N. Rzhiga, Z. G. Trunova) on 4[illegible]-cm wavelengths. Effective temperatures and values of radiation flux were determined and also the dimensions of radiation belts of the planet. Although in the region of observations of radio emission from Jupiter our radio astronomers still lag behind foreign astronomers, still (as also in many other questions of astrophysics) theoretical research on the radio emission of Jupiter in our country is very successful. Just so, V. V. Zheleznyakov from 19[illegible] began a theory of sporadic radio emission from Jupiter, according to which the source is plasma oscillations in the ionosphere of the planet (taking into account the influence of its magnetic field). V. V. Zheleznyakov examined also the origin of decimeter radio emission of Jupiter. His results are summarized in a monograph (1964).

Saturn

Considerably less attention in our country has been given to studies of Saturn. The absence on its disk of noticeable details (besides the white spot appearing in 1933) did not attract the attention of visual observers.

Photographic photometry of Saturn was started already in 1909 by G. A. Tikhov at Pulkovo. The photometric observations of Saturn were continued in 1933 by N. P. Barabashov and B. Ye. Semeykin in Kharkov, and in 1935 and 1937 by V. V. Sharonov (AO of Leningrad State University) at the Erevan and Pulkovo observatories. Pictures of the distribution of brightness along the equator and isophots for the whole disk were studied, and Sharonov conducted visual absolute determinations of the brightness factor of the planet. The white spot of 1933 was observed photographically by N. P. Barabashov in infrared rays for two years.

Photometry of the rings of Saturn was carried out by N. P. Barabashov (1950), V. D. Furdylo (1941) and V. N. Lebedinets (1954), studying photometric cuts, color of rings and change of their brightness with phase (in the interval of phase angles from 16' to 1°).

Of great value was theoretical research of light scattering by

the rings of Saturn, conducted starting from 1940 by M. S. Bobrov. In his works a physical interpretation is given of the phase curve of the rings of Saturn, the shadow effect is studied, estimates are made of the dimensions of particles, thickness, volume density and mass of rings.

Spectrophotometry of Saturn and its rings was produced in 1957 by V. G. Teyfel' and Ya. A. Teyfel'. It revealed a distinction in the color of Saturn itself and the rings (disk of the planet is redder). Furthermore, contours of methane banks 6190 Å in the spectrum of Saturn were studied.

Radio emission of Saturn in the decimeter range was theoretically studied by V. V. Zheleznyakov (1964a), being explained, as in the case of Jupiter, by synchrotron radiation of relativistic electrons in the radiation belts of the planet.

Uranus

This planet both here and abroad has been studied only episodically. In 1934 P. P. Parenago photometrically determined the period of rotation of Uranus – 10 hours 49 minutes – in good agreement with other determinations.

In 1956-1960 V. G. Teyfel' at the Dept. of Astrobotany AS Kazakh SSR made a spectrophotometric study of Uranus and determined its color indices: visible and true (corrected for the influence of the absorption bands of methane). Contours of four methane bands were studied also.

Minor Planets and Planetary Satellites

In the discovery and study of small planets the Soviet scientists hold an honorary place in world science. For many years the Simeiz Observatory occupied second place in the world in the number of discovered minor planets (G. N. Neuymin, S. I. Belyavskiy and others), until "exhausting" the planets accessible to the Simeiz double

astrograph changed this position. After the war observations of the minor planets were renewed at Simeiz (1948-1956), Alma Ata, Vil'nyus, Kazan, Kiev, Moscow and Tartu.

Calculations of orbits and composition of the ephemerides of the minor planets after 1945 was concentrated at the Institute of Theoretical Astronomy AN SSSR in Leningrad, which since then has been the world center on definitization of orbits and publication of the ephemerides of the minor planets. At the institute a series of new methods of calculation of orbits and ephemerides was developed (taking into account perturbations) using electronic computers.

Physical observations of asteroids were conducted by Soviet astronomers systematically. Let us note the photometric and colorimetric observations of V. P. Tsesevich (especially his investigation of changes of brightness of Eros in 1930-1932), I. I. Putilin (1929-1953), A. N. Deych (1935-1939), N. S. Orlova (1939), Ye. K. Kharadze (1940-1942), Ye. V. Sandakova (1950-1955), V. G. Riyves (1952-1955) and others. In these observations phase curves, color indices and short-period fluctuations of the brightness of series of asteroids were determined.

During the last few years investigations of physical properties of asteriods employed the spectrophotometric method. In 1956-1960 V. G. Teyfel' carried out spectrophotometry of Vesta and Evnomin. He determined color indices and spectrophotometric gradients, while for Vesta a periodic change of color was detected (a change of its brightness was known long ago).

Many scinetists studied the problem of origin and disintegration of asteroids. Let us note here the work of V. G. Fesenkov, N. M. Shtaude, S. V. Orlov, I. I. Putilin, V. V. Radziyevskiy, O. Yu. Shmidt, B. Yu. Levin and their colleagues. The state of our knowledge about the minor planets in 1953 is summarized in the monograph of I. I. Putilin "The Minor Planets." A valuable supplement to it are surveys N. S. Samoylova-Yakhontova, published in 1960.

Most of the work about planetary satellites was dedicated to the study and explanation of observed acceleration in the motion of the Martian satellite-Phobos (M. P. Kosachevskiy, 1954; I. S. Shklovskiy, 1959; N. N. Pariyskiy, 1960; V. V. Radziyevskiy, V. P. Vinogradov, 1964). Several hypotheses explaining this phenomenon have been offered: retardation in external layers of the atmosphere of Mars (I. S. Shkolovskiy), tidal braking (N. N. Pariyskiy), pressure of radiation on bodies of irregular shape (V. V. Radziyevskiy and V. P. Vinogradov). However, the real cause of this phenomenon, if it exists, still remains open.

In 1964 V. I. Morcz investigated infrared spectra of the satellites of Jupiter - Io and Ganmede, showing an absence of methane and ammonia bands in them.

As we see, studies of the planets in the USSR have progressed successfully, especially photometry, spectrophotometry and theoretical works. Even newer results are given by radio astronomical methods of observation. We need not doubt that guaranteeing the Soviet planetary leaders large telescopes, located in points with best conditions of the astroclimate, will have a beneficial effect on further development of planetary studies in our country.

THE COMETS

Soviet cometary astronomy inherited rich traditions of founder of science about comets of Fedor Aleksandrovich Bredikhin: wide generalized data of observations on the basis of contemporary theory and consistent penetration into the mechanism of cometary phenomena.

For 50 years in the USSR all divisions of cometary astronomy expanded, both observational and theoretical.

The basic center of cometary astronomy during more than 30 years was Moscow, where cometary studies in 1922-1958 were directed by S. V. Orlov (1880-1958). During the last 20 years similar centers appeared also in Kiev, Dushanbe, the Baltic states; the journal "Comets and Meteors" was founded.

In the USSR was 14 new comets discovered (see table).

Mechanical theory of cometary forms. One basic problem of the mechanical theory of cometary forms is the determination of forces on particles of the cometary tails, which leads to finding their accelerations. The latter usually are expressed in parts of the acceleration of gravity force to the sun and are designated by symbol $1 + \mu$, where μ – relation of the force of radiation pressure to gravity force.

Knowledge of $1 + \mu$ gives a basis for the solution of another

Comets discovered by Soviet astronomers.

Number		Surname of discoverer	Coauthors of discovery
Final	Provi-sional		
1921 I	(1921c)	A. D. Dubyago (Kazan)	
1921 II	(1921a)	"	Reed (Capetown, South Africa)
1923 III	(1923a)	"	Barnard (Madrid, Spain)
1925 VI	(1925a)	G. A. Shayn (Simeiz)	Comas-Sola (Barcelona, Spain)
1929 III	(1929b)	G. N. Neuymin (Simeiz)	–
1936 III	(1936b)	S. M. Kozki (Tashkent)	Kao (Kannopa [?], Japan) Liess (Mountain Obs., Carpathian mountains)
1936 IV	(1936c)	G. N. Neuymin (Simeiz)	Jackson (Johannesburg, South Africa)
1939 I	(1939a)	S. M. Kozki (Tashkent)	Peltier (Delphos, United States)
1939 III	(1939d)	I. V. Akhmarov and S. N. Yurlov (Udmurt. Autonomous SSR)	Cassel (Hokksund, Norway)
– *	(1939i)	B. I. Kaminskiy (Tashkent)	–
1943 I	(1942g)	G. A. Tevzadze (Abastumani)	Whipple (Harvard, United States) Fedtke (Koenigsberg, Germany)
1949 VI	(1949e)	P. F. Shayn (Simeiz)	Shaldac (Lovell Obs. USA)
1955 IV	(1955f)	A. M. Bakharev (Dushanbe)	MacFarlane, Krinke (Seattle, Canada)
1957 IX	(1957f)	I. N. Latyshev (Ashkhabad)	Wildt (Bern, Switzerland) Barnum (Arizona, United States)

*A final number has not been conferred, since due to the small number of observations the orbit was not calculated.

important problem — classification of cometary tails, principles of which were developed by Bredikin.

According to Bredikin, type I includes tails which have $1 + \mu$ of the order of several tens; tails of type II have a value of $1 + \mu$ of the order of units; tails of type III are characterized by $1 + \mu$ of the order of fractions of one. To this division also corresponds the distinction of the physical nature of tails: type I — plasma; II — dust, finely-dispersed with possible presence of neutral gases; III — dust, roughly-dispersed. Anomalous tails are directed not from the sun, as is usual, but to the sun and present, according to Bredikin, the initial phase of the formation of meteor showers, generated by the nucleus of the comet.

After Bredikhin's new methods of determination of relative accelerations $1 + \mu$ in the tails of comets were given by A. Ya. Orlov (1910), S. V. Orlov (1935) and N. D. Moiseyev (1925). The theory of anomalous tails was developed by S. K. Vsekhsvyatskiy (1932). The motion of particles in a resisting medium is examined in series of articles by G. N. Duboshin and his colleagues (see M. F. Subbotin, 1948) and O. V. Dobrovo'skiy (1961b). Convenient formulas were developed for the transformation of cometcentrical coordinates (S. K. Vsekhsvyatskiy, 1929; S. V. Orlov, 1935). Along with formulas of German scientist Stumpf (1956) and theory of projection of cometary forms of Arend (1959) they permit establishing by the visible outlines of cometary tails the true dimensions and form of tails, disposed actually not in a picture plane, but in the plane of the cometary orbit. and solving the inverse problem of determination of visible orientation of cometary tails on the firmament if their location in the plane of the cometary orbit is assigned.

Various researchers studied a great number of cometary tails. In particular, relative accelerations were measured ($1 + \mu$), which attained 2000-3000 in tails of type I (see, for example, B. A. Vorontsov-Vel'yaminov, 1930; G. K. Nazarchuk, 1959, and others), 2.0 and 0.6 respectively in tails of type II and III (S. V. Orlov, 1935) and 0.0-0.1 — in the heads of comets (O. V. Dobrovol'skiy,

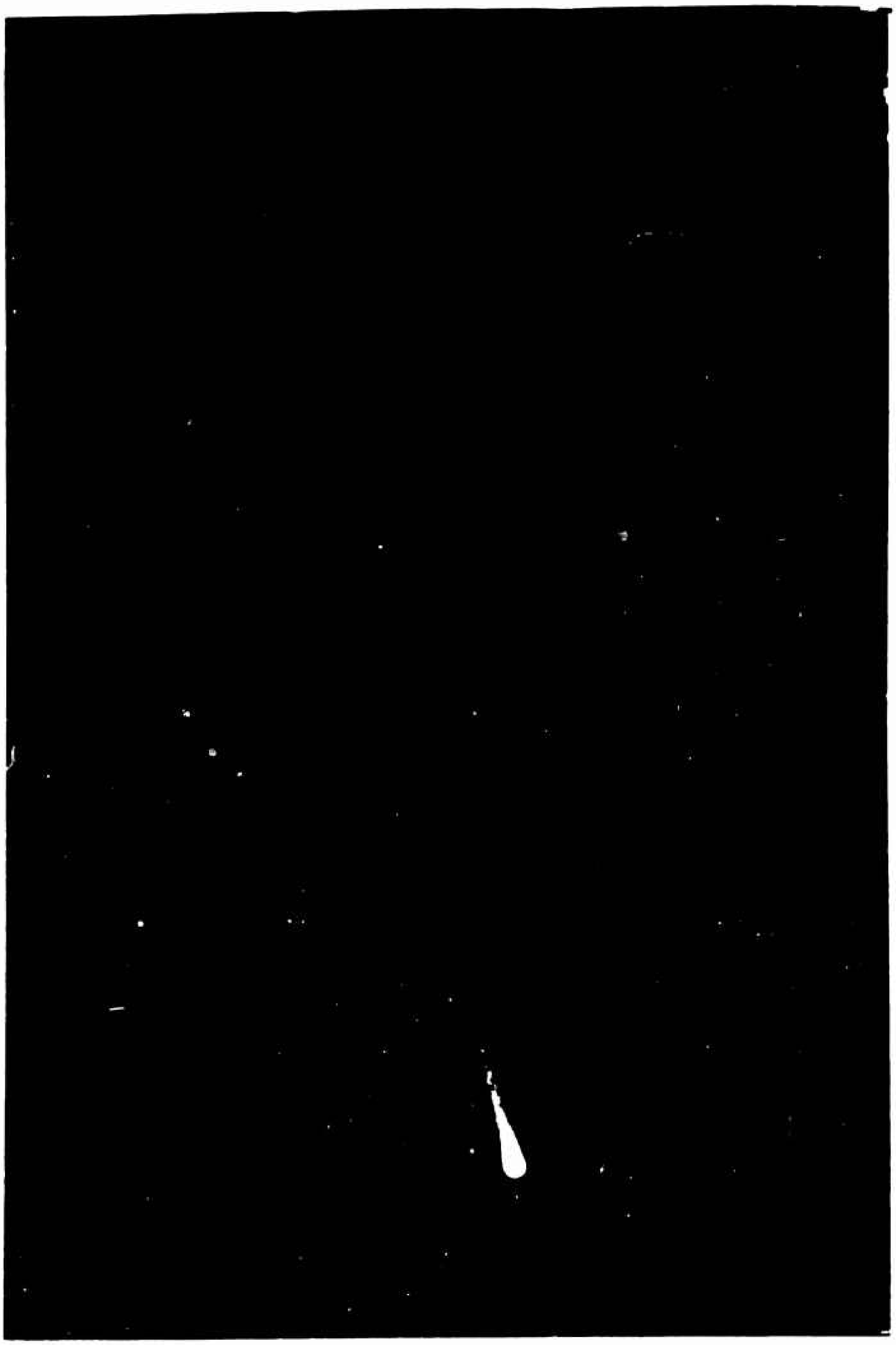
Sergey Vladimirovich
Orlov

1880-1958

1961b). Types of tails were also determined and a catalog of 169 cometary appearances (A. A. Demenko, 1964b) was composed.

Precision methods of calculating the orbits and ephemeris of cloud formations in tails of type I, developed in the above mentioned articles of A. Ya. Orlov and S. V. Orlov, at present have only historical interest, but in their own time they played an important role in the appearance of new directions in the theory of tails of type I, since their application made evident the insufficiency of the theory of classical mechanics and the necessity of acquiring additional forces of a nonmechanical nature.

Conversely, in the theory of tails of types II and III, consisting of dust particles, application of classical methods is very natural, and one should consider fully justified the appearance of tables, facilitating the synchronous and syndyname construction and finding the moment of departure of particles and their acceleration



Comet 1939 III, discovered 15 April 1939 by I. V. Akhmarov and S. N. Yurlov (photograph of the Zonneberg Observatory).

or ied coordinates, for example the table of E. Fayziyev (1962, 1 d also the appearance of highly effective methods of approximate calculation of tails (O. V. Dobrovol'skiy, Kh. Ibodinov, 1967). Work similar to that conducted by Fayziyev was done in England by Meek, but the tables of Meek were never published.

Let us note certain results of the investigation of individual comets.

N. D. Moiseyev (1925) examined work of Bredikhin about the main tail of comet 1901 and found that it is synchronous, and not syndyname, as Bredikhin thought. S. K. Vsekhsvyatskiy (1932) revealed that anomalous tails of comets 1823, 1877 II, 1886 II in reality are synchronous tails of type III. A classic example of such a pseudo-anomalous tail in recent time is the lanceolate branch of the comet Arend-Rolan 1957 III, investigated by Soviet and many foreign authors and appearing also as a synchronous tail of type III.

S. V. Orlov (1944), developing the idea of F. A. Bredikhin, explained the strange formation near the head of the great comet of 1882 II as a projection of a remote part of the twisted tail of the comet onto the head region. At the same time investigations of separate comets showed that habitual attempts to adjust tails of comets of types II and III always as synchronous or syndyname are too stereotyped and impoverish the true nature of the phenomenon. Thus, for example, the main tail of comet 1957 III according to separate photographs allowed fitting under one of the standard curves, as also was done by the Frenchman Gige, but joint analysis of many postitions of the tail showed with certitude that it was neither synchronous nor syndyname, but represented the result of a continuous outflow of particles having different accelerations (O. V. Dobrovol'skiy, E. Fayziyev, Kh. Ibodinov, 1966).

Thorough study of the main tail of another bright comet, 1957 V. Mrkosa, intersected by numerous lines – end synchronous by classical theory – put under boubt the correctness of classical interpretation of end synchronous in general, (S. K. Vsekhsvyatskiy, 1959). If the

orientation of lines, closer to the direction to the sun than was expected, can be explained by the initial speed of ejection oriented along the axis of a tail of type I as the German astronomer P. Notni (1964) did, then the briefness of their visibility remains not quite understandable. A similar pseudosynchronous picture was observed in the tail of the comet Seki-Layns 1962 III (Demenko, 1964a). Therefore the opinion of S, L. Vsekhsvyatskiy (1959) about the fact that not only in the tails of type I, but also in formations of, at least certain, details of tails of type II nonmechanical forces take part is not deprived of foundations.

These works permitted Soviet science in the region of the theory of cometary forms and after Bredikhin to preserve a leading role in world science.

Photometry. Even in the pre-October period S. V. Orlov proposed the later widely-used formula

$$E = E_0 \Delta^{-2} r^{-n},$$

or in stellar magnitudes

$$m = m_0 + 5 \lg \Delta + 2{,}5 n \lg r,$$

connecting the visible brightness of a comet m, or illuminance E created by it, with heliocentric r and geocentric Δ distances of the comet. Another well-known empirical relationship belongs to Vsekhsvyatskiy:

$$m = m_0 + 5 \lg \Delta + z (r^n - 1),$$

where m_0, n and z are constants. Regular determination of photometric parameters m and n permitted conducting a series of interesting statistical investigations, in particular to reveal secular weakening of brightness; the mean value of n was found close to 4 (S. K. Vsekhsvyatskiy, 1958, 1962, 1964).

Besides general methods of the photometry of extended objects (N. N. Sytinskaya, 1948), special methods of the photometry of comets were developed and used: focal and extrafocal joining to stars (V. G. Riyves, 1946, 1957b; V. P. Konoplev, 1959, 1961, 1962 and others); photometry of monochromatic images of comets (B. S. Shul'man, 1947; B. A. Vorontsov-Vel'yaminov, 1954); electrophotometry and polarimetry of comets began to be successfully used. Excellent isophots of comets, competing with the best foreign, were constructed. This permitted Soviet astronomers to study in detail the distribution of surface brightness I and volume luminosity N in the monochromatic heads of many comets. For the majority of comets $N \sim R^{-\gamma}$, where R – distance from nucleus, and γ – index, as a rule, smaller than 2. Typical numerical values of N for central regions of the head turned out to be from several tens to 10^{11} radiating molecules per cubic centimeter. The general number of molecules in the head of a comet N_0 is estimated from 10^{30} for the weakest comets to 10^{38} for the especially bright comet 1882 II (S. M. Poloskov, 1951).

Huge statistical material on physical characteristics of comets has been collected in the unparalled major monograph Vsekhsvyatskiy (1958), continuing the tradition of the famous collections of Golechek, published at the end of the XIXth and beginning of the XXth Centuries in Vienna.

The theory of isophots of comets intensively expanded, the beginning of which was the well-known works of D. O. Mokhnach (1938, 1956, 1958). In particular, it was found that during uniform outflow of nondestroyed particles, i.e., when $\gamma = 2$, and arbitrary direction of acceleration of the force of radiation pressure

$$I \sim R^{-1}$$

(law of Mokhnach, well justified for many comets). Considering an outflow of substance nonuniform in various directions, the photometric center of the head cannot coincide with the gravitational center and because of this generates systematic errors in elements of orbits (Mokhnach, 1956). In recent years more complex models were examined,

when initial velocities of particles are not identical; for example, they have Maxwellian distribution (A. V. Kurchakov, 1960), when particle can change speed by a jump within the limits of the head in the process of photodissociation (V. G. Riyves, 1960a, 1964 and others). V. G. Riyves developed also an interesting method of determination of the speeds of molecules by the apparent distribution of brightness in the head of the comet. First his application for thermal velocities of maternal molecules directly separated from the nucleus gave a value of the order of $3 \cdot 10^4$ cm/s, and for speeds of radicals – products of their dissociation – a mean value of from $6 \cdot 10^4$ to $1.5 \cdot 10^5$ cm/s (V. G. Riyves, 1963), well agreeing with experimental data on photodissociation.

The most exhausting theory of isophots, embracing both the majority of Soviet and foreign models of Wallace and Miller (1958) and Kaiser (1957), was put together by A. Z. Dolginov and Yu. N. Gnedin (1966).

Intense polarimetric investigations of comets began here and abroad chiefly in connection with the appearance of the bright comets 1957 III Arend-Rolan and 1957 V Mrkos. The majority of observers in comparatively good mutual agreement obtained a degree of polarization of the glow of comets up to 20-30% and orientation of the plane of preferential oscillations of the electrical vector approximately normal to the radius-vector. By photographic means such results were obtained in particular by L. V. Mirzoyan and E. Ye. Khachikyan (1959) in Byurakan, D. L. Astavin-Razumin (1960a) in Kuchin, D. A. Rozhkovskiy and A. V. Kurchakov (1960) in Alma Ata, Blackwell and Wilstrop (1957) in England; electrophotometrically – P. N. Boyko and A. V. Kharitonov (1957) in Alma Ata, Bappu and Sinvkhal [Translator's Note: exact spelling not found] (1960) in India. The biggest values of polarization were registered in normal and anomalous tails of the comet Arend-Rolan (to 55%, D. L. Astavin-Razumin, 1960a) and in the head of the same comet (to 45%, N. Richter, 1961). Many researchers have noted the growth of the degree of polarization with a transition from head to tail, for example the Czechs Blaha, Hruŝka, Ŝvestka and Vanisek (1958). The effect was explained by the distinction in the

contents of gas and dust (various polarization ability) in the head and tail of the comet. It was found identical in rays of various color (M. Martel', 1959, 1960). D. L. Astavin-Razumin (1960a, b) showed that this effect has an inconstant character and for such a small period as 3 hours the distribution of polarization in the tail can change.

Soviet researchers found that there are considerable local deflections from average also for the direction of the plane of polarization, which are connected with the ejection of powerful streams of substance from the nucleus (L. V. Mirzoyan and E. Ye. Khachikyan, 1959). Yu. N. Lipskiy (1957) in Moscow established that the direction of the plane of preferential oscillations depends also on the wavelength of light dispersed by the comet. Polarization observed by Soviet and foreign astronomers is explained as the result of diffuse reflection from dust particles of the order of a micron in size, and as the result of resonance fluorescence of cometary gases.

Burst of glow. Sudden changes of glow imposed on a smooth light curve are characteristic for many comets, especially for weak comets. Sometimes changes of general brightness (chiefly a drop) are connected with the fission of cometary nuclei, but more frequently they occur for some other causes. In the USSR the study of these causes began even in 1923 by S. V. Orlov, showing on the example of Halley's comet 1910 II the close connection of brightness of the nucleus with solar activity, as the index of which he selected the Wolf number (S. V. Orlov, 1923). He showed that the head of a comet on the whole does not react to Wolf numbers. Hence it was possible to conclude that the head of small comets, in which the brightness of the central near-nucleus part plays a basic role, also will be sensitive to solar activity. This indeed was shown for the majority of investigated comets having a fluctuation of brightness, although not for all (see, for example, Yu. V. Filippov, 1929; O. V. Dobrovol'skiy, 1961b).

S. V. Orlov proposed another explanation of the bursts — collision of the nucleus with a meteorite. Such encounters are improbable, but jointly with the mechanism of F. L. Whipple (1950, 1951) - spontaneous

destruction of the very friable surface layer of the nucleus in the process of sublimation – can explain the bursts not connected with solar activity. Regarding the latter, the mechanism of its influence has been studied long ago, but it is still not clarified in sufficient measure. The change of the speed of sublimation under the effect of corpuscular streams passing from the sun is one of the probable causes, but it is doubtful whether it is the only one.

Soviet work on study of the connection of the phenomenon of a comet with solar activity stimulated numerous investigations abroad, especially in Czechoslovakia (see, for example, Z. Sekanin, 1960).

Nature of the nucleus. Structure of the nucleus and processes in it determine in the end the whole phenomenon of the comet. Therefore the constant interest of researchers in the theory of the nucleus is understandable. In this question throughout all history Soviet science has played one of the main roles.

For a long time in Soviet science there coexisted two equal models: the nucleus as a more or less compact swarm of meteoric particles (A. D. Dubyago, 1950; V. G. Fesenkov, 1964) and the nucleus as one or several monolithic chunks (S. V. Orlov, 1935; B. A. Vorontsov-Vel'yaminov, 1945). At present the majority of researchers leans toward the second point of view as the most effective, although the model of the nucleus-swarm has not been abandoned.

The theory of the cometary nucleus with gases adsorbed in it was first developed by B. Yu. Levin (1943). From the expression for the speed of gas liberation, following from the theory of desorption, he obtained the now widely-known expression for the brightness of a comet in stellar magnitudes:

$$m = A + B\sqrt{r},$$

where A and B are constants. This formula replaced the empirical relationship of S. V. Orlov.

Vasiliy Grigor'yevich
Fesenkov

A. D. Dubyago (1948) by means of celestial-mechanical calculations first indicated the comparatively large relative decrease of the mass of a nucleus after one passage near the sun: the loss of mass and the connected momentum, at least for certain comets, turned out to be so great that orbital elements of the comet considerably change. This permitted Whipple (1950, 1951) to justify convincingly his model of the nucleus as a conglomerate of ices, independently proposed also by Vsekhsvyatskiy (1948). In this now almost conventional model degassing occurs no longer only due to desorption or activated diffusion, as Riyves considered (1952), but basically as a result of sublimation of ices and the flow of forming gases through a friable dust layer, possible covering the surface of bodies composing the nucleus of the comet. The form of Levin's formula remains constant. Later calculation of heat transfer inside the nucleus, not foreseen in the initial theory of Levin, lowered the index of r and led to the generalized formula

$$m = A + Br^{\alpha}, \ \alpha < 0{,}5,$$

i.e., to a theoretical foundation of a variant of the formula of S. K. Vsekhsvyatskiy. A generalized formula was obtained almost simultaneously and independently by M. Z. Markovich in the USSR and A. Weigert in Germany.

Integration of heat-conduction equations taking into account losses on radiation and sublimation permits calculating theoretically coefficients B and α and comparing them with observations. On the basis of such integration, conducted in 1963 by the numerical method, M. Z. Markovich showed that the closest light curve to observations comes from a nucleus with properties close to ice H_2O. Conversely, ices close in properties to highly volatile solid CH_4 in no way can be the basic component part of cometary nuclei (O. V. Dobrovol'skiy, 1966).

Nature of cometary atmospheres. The beginning of research in the physics of cometary atmospheres in the USSR was the works of G. A. Tikhov, G. A. Shayna, S. K. Vsekhsvyatskiy, S. V. Orlov, B. S. Shul'man, obtaining and interpreting in prewar years (published after the war) the spectra of certain interesting comets (B. S. Shul'man, 1947; S. A. Shorygin, 1948). In recent time spectroscopic investigations are conducted episodically at many observatories (Pulkovo, Abastumani, Byurakan, Crimea, Moscow, Kiev, Alma Ata, Dushanbe and others). As a result in cometary atmosphers the presence of a great number of free radicals is confirmed, such as C_2, C_3, CN, CH, OH, NH, NH_2, N_2+, CO+, and others, Na atoms, dust particles; their prevalence in comets is studied. However, the basic centers of cometary spectroscopy both observation and theoretical continue to remain in Belgium, France and the United States. At present and where we live, in considerable measure under the influence of the program of the International Year of the Quiet Sun, the problem of organization of a spectroscopic service of comets using large instruments like those existing in the West has been posed.

Theoretical research on the physics of cometary atmospheres in our country is connected in considerable measure with the name of a pupil of S. V. Orlov — S. M. Poloskov (Moscow), whose main work

Aleksandr Dmitriyevich
Dubyago

1903-1959

was in the decade of 1947-1956. Poloskov investigated the relative effectiveness of different mechanisms of the glow of gases under conditions of comets and confirmed the well-known conclusion of Swings that the basic role belongs to resonance reemission of sunlight by molecules (S. M. Poloskov, 1948a, 1951). He studied the probability of ionization by solar radiation and found that it does not ensure the observed abundance of CO+. This conclusion was confirmed in Dushanbe by O. V. Dobrovol'skiy (1964) on the basis of the latest rocket and laboratory data.

Proceeding from the position about the fact that in cometary atmospheres the overwhelming majority of molecules is in the lowest electron state and therefore only resonance series are excited, Poloskov analyzed conditions of visibility of different molecules whose presence was probable. He concluded that independently of the true chemical composition of the atmosphere the basic emissions in

the visible region of the spectrum must be CN and C_2 resonance series, and among ionized molecules — CO^+ bands, which explained the visible abundance of CN, C_2 and CO^+. This permitted him to make the conclusion that the full density of the cometary atmosphere is at least an order higher than the partial density of a cyanic atmosphere or an atmosphere from carbon monoxide (S. M. Poloskov, 1956). Numerous spectral observations showed the presence and unforeseen Band emissions and a dependence of the appearance of the spectrum on the chemical structure of the comet, but the conclusion concerning high general density of the atmosphere, following also from other considerations, was confirmed. Latest investigations of forbidden lines of oxygen in the spectra of comets showed that the general density of the atmosphere must be increased by several orders as opposed to that given by photometry (L. Biermann and Ye. Trefftz, 1964).

In connection with this the problem of chemcial reactions in the region of the head close to the nucleus indicated by Dobrovol'skiy (1961) becomes especially interesting. In particular, the probability of all possible ways in comets of the disintegration of molecules NH_3, $(CN)_2$, H_2O, CO_2, CH_4, and several other hydrocarbons, calculated by V. I. Cherednichenko (1956), must be augmented by probabilities of certain of the simplest binary reactions between them and products of their disintegration. The latter is only partially done in the mentioned work of Biermann and Trefftz, explaining the appearance of CO^+ by chemical reactions between ions and neutral molecules.

S. M. Poloskov (1948b, 1949) studied radiation pressure on gases of cometary atmospheres and the connected differentation of substance in the head of the comet. He, in particular, showed that the high acceleration observed in tails of type I cannot be the result of radiation pressure. Conversely, acceleration in tails of type II can be easily explained by the radiation pressure on molecules.

Radiation pressure on the dust component also was the subject of consideration of Soviet astronomers. After the first work of S. V. Orlov (1935) there appeared a more detailed study by B. Yu. Levin, finding that radiation pressure on dust particles is sufficient to explain accelerations only in tails of type III, but not of type II.

Hence, and also from the analysis of certain spectrograms obtained with the objective prism, he made an important conclusion concerning the gaseous nature of tails of type II (B. Yu. Levin, 1947). However, this conclusion is impossible to consider final. On one hand, the density of dust particles can be less than accepted by Levin in view of their possible friable nature (and, consequently, acceleration is greater). On the other hand, photometry of the head and tail of type II of the bright comet 1957 III showed that practically all substance of the head, containing both gas and dust, passed into the tail (V. G. Riyves, 1960a, b). Therefore the majority of researchers at present has declined to decide on a combined gas-dust nature of tails of type II. Very necessary are good slit spectrograms of tails of type II in order to finally decide this question. Between the acceleration of dust particles $1 + \mu$ and their initial speed v is an interesting dependence. It was studied by P. B. Babadzhanov (1951) and in greater detail by O. V. Dobrovol'skiy (1961 and 1966), finding that $1+\mu \propto v^2$, as should be during the ejection of dust by the gas flow from the nucleus.

Electrodynamics of comets. This is one of the youngest divisions of cometary astronomy, born as a science after H. Alfvén provided a foundation in 1942 for magnetohydrodynamics, although the considerable role of electrical forces in comets had already been expressed in the XVIIIth Century, and in special astronomical literature from the middle XIX Century. It was given the attention of such classics in astrophysics as Bredikhin and Eddington. Basic in this region was the work of L. Biermann (1951) and H. Alfvén (1957), in which concrete patterns are given of the interaction of corpuscular streams of the sun with cometary atmospheres.

Biermann's scheme – the transmission of momentum to the cometary atmosphere by means of paired interactions of cometary ions with electrons and electrons with protons of the flow – was augmented by O. V. Dobrovol'skiy (1961) by means of the calculation of distant interactions.

Alfvén's scheme, first using in consideration magnetic fields and treating the beam structure of tails of type I as materialized

lines of force of the magnetic field of the corpuscular stream frozen in the comet, was expanded and augmented by various (including many Soviet) scientists. Dobrovol'skiy (1962) first examined quantitatively the question about a corpuscular stream being shielded by the head of a comet. L. S. Marochnik (1964a) laid the foundation of the theory of shock waves appearing during the interaction of a magnetized corpuscular stream with cometary plasma. Many works of L. S. Marochnik, Z. M. Ioffe, N. G. Ptitsyna are dedicated to the calculation of forms of lines of force and comparison of them with observations (see L. S. Marochnik, 1964b). These works considerably supplemented and definitized theoretical research conducted abroad on the interaction of the tails of comets with corpuscular streams.

As a result the qualitative scheme of Alfvén obtained quantitative confirmation, and the role of the stream of corpuscles from the sun in the formation of tails of type I became evident. The high accelerations and also motion of rays like ribs of a closed umbrella were explained. However, certain questions still await a solution. For example, the role of electrostatic fields, whose value was indicated S. B. Pikel'ner and O. N. Mitropol'skaya (1948) and O. V. Dobrovol'skiy (1961b), has not been completely clarified; the theory of acceleration of separate structural formations in tails of type I has not been developed; the concrete mechanism of the separation of plasma of a tail into separate rays or the appearance of such forms of motion of substance in comets as pendulum-like oscillations of the tails (A. Malayz [Translator's Note: exact spelling not found], 1963), periodic compression and expansion of the components, random motion of separate formations across the tail (K. Rudnitskiy, K. Ye. Kirns, 1965).

Experimental cometary astronomy is the youngest, most rapidly expanding and promising division of science. The number of its basic problems already includes a laboratory reproduction of the phenomenon of the comet, calculation, creation and observation of artificial comets in circumterrestrial space; in the near future it will include sending research rockets to natural comets, and in view is sending manned artificial comets to the sun.

Research laboratories and groups with such problems appeared almost simultaneously in different countries, which in considerable degree promoted corresponding solutions accepted at the XI and XII Congresses of the International Astronomical Union (IAU).

The program of laboratory investigations officially declared in the United States included the study of the behavior of different possible components of the nucleus under the joint action of corpuscles (protons) and electromagnetic radiation. An analogous problem was solved by the Institute of Astrophysics of the Academy of Sciences of the Tadzhik Soviet Socialist Republic in collaboration with the Institute of Physical Chemistry of the Academy of Sciences of the USSR and has been posed at other establishments of the USSR. In particular, it was found that such substances as solid H_2O and CO_2 sublimate under the influence of a corpuscular streams faster than in the same conditions but in the absence of irradiation. At the Physical and Technical Institute of the Academy of Sciences USSR im. A. F. Ioffe under the leadership of Acad. B. P. Konstantinov the sublimation of H_2O and CO_2 ices is being studied; the formation of a dust matrix on the surface of ices enriched with dust and its drop with a flare of brightness is being reproduced in the laboratory (Ye. A. Kaymakov and V. I. Shirkov, 1967) and others.

A certain preparation for work in the second direction is the observation of "artificial comets," i.e., sodium, ammonium, etc., clouds thrown-out by rockets at high altitude. Such work also is being conducted in many countries.

"Artificial comets" created by Soviet space rockets were observed by photographic and electron-optical methods at many observatories of the USSR. In form they were similar to cometary halos and had an expansion rate ($\sim$1 km/s), also typical for halos; their observations present interest for the study of properties of the medium in which expansion occurs (see the section "Space research...").

Cosmogony. Cometary cosmogonic theories can be divided into two large groups: developing ideas of Laplace (interstellar origin)

and Lagrange (conception in the planetary system).

Theories of the first group were investigated in a cycle of work by N. D. Moiseyev, I. P. Tarasashvili (see N. D. Moiseyev, 1948). The majority of researchers at present does not share the Laplacean point of view. The most serious argument against it is investigations of the initial orbits of comets, most of which is carried out in the USSR, primarily by I. V. Galibina (1958, 1963), calculating according to a method specially developed by S. G. Makover the initial orbits of more than 50 comets, and also A. A. Mikhaylov, M. Ya. Shmakov, M. A. Dirikis, O. N. Barteneva and others. It turned out that initial orbits always have positive reverse semiaxes 1/a, corresponding to elliptic orbits; unit negative 1/a, corresponding to hyperbolic orbits, lie within limits of errors of determination.

Thoeries and hypotheses of the second group are detated the most animatedly. They include the assumption of S. V. Orlov (1948) about formation of comets as a result of separation of asteroids upon collisions with meteorites, subjected to criticism from the side of Moiseyev (1948). The subject of rather passionate discussio- among a great number of cosmogonists is the hypothesis about the ejection of comets from large planets or their satellites, revived in our time by S. K. Vsekhsvyatskiy (1932).[1] V. A. Krat (1956) advances a hypothesis about simultaneous formation of planets and comets, in which comets are examined as a thickening, formed in the process of gravitational condensation of remnants of prestellar substance.

Expressed and other hypotheses. A direct check of the theory of S. K. Vsekhsvyatskiy was undertaken by means of celestial mechanics, attempting with the greatest possible accuracy to calculate a series of comets closely approaching Jupiter; however a straight substantiation of Vsekhsvyatskiy's position has not been achieved. Though the theory of Vsekhsvyatskiy could explain certain peculiarities of

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[1]Such an idea was expressed even in the XVIIIth Century.

observed motion of comets, the idea of comet-forming explosions on satellites frightens the majority of cosmogonists; primary efforts at present are directed towards development of the ideas of J. Oort (1950) about a ring of comets in the solar system near the boundary of the sphere of action of the sun, supplying the observed comets thanks to the perturbing action of stars (S. G. Makover, 1964).

The most considerable cycle of works is the cycle dedicated to finding the distribution function of comets arriving from an Oort cloud, in reference to 1/a and other elements of orbits under planetary influence in the first place of Jovian (Jupiter), perturbations taking into account disintegration of comets (K. A. Steins, 1961a, b; K. A. Steins and E. P. Riyekstyn'sh [Translator's Note: exact spelling not found], 1960). This cycle of works develops the vies of N. D. Moiseyev (1948) and other foreign authors (1948, 1950). The theory will agree satisfactorily with observations in a number of cases. However, it is very far from perfection, and intense work continues.

Recently numerical methods of integration using electronic computers have received every increasing prominence. As a result there is a calculated series of initially circular orbits in the Oort belt transformed under the action of the general gravitational field of the galaxy into ellipses and hyperbolas (G. A. Chebotarev, 1964) (see als the section "Celestial mechanics"). In this direction one should expect the most interesting results about the origin of mysterious strangers from space.

METEORS AND METEORITES

Meteors

Meteors are light phenomena occurring in the terrestrial atmosphere and observed in the form of stars speeding through the heavens. Frequently after the flight of a bright meteor, usually continuing only fractions of a second, on its path remains a weakly luminescent trail, which vanishes after several seconds.

Meteors cause an invasion into the atmosphere of the earth of hard grains, so-called meteor bodies or particles. Noneless the frequently even specialists refer to as meteors not only the light phenomena, but also the actual meteoric particles even when they are in interplanetary space (V. V. Fedynskiy, 1960). In reality, meteors as a phenomenon appear at a height of nearly 120 km and vanish at a height of nearly 80 km.

The study of meteors in our country began in the 1830's. In 1832 at Kursk the talented self-taught astronomer F. Semenov observed the Leonid meteor shower and at the same time assumed a connection of meteors with comets. At the end of the past and the beginning of this century the study of meteors occupied the most prominent Russian astronomers F. A. Bredikhin, V. K. Tseraskiy, S. P. Glazenap, K. D. Pokrovskiy, S. N. Blazhko, G. A. Shayn and others. However, only after the Great October Socialist Revolution did the study of meteors in our country take a systematic character, proceed systematically with the application of new improved methods and

become widely expanded. Abroad extensive visual observations of meteors were conducted in Canada — under the leadership of Millman, in England — under the leadership of Prentice and then Denning and in the United States under the leadership of Olivier, where even in 1911 the American meteoric society was founded.

In the 1920's in our country the mass visual observations of meteors, started already at the beginning of this century were renewed, conducted at many points by both individual amateur astronomers and also collectives of observers. For example, systematic observations for several years were conducted in Leningrad, Vitebsk, Kursk, Trubchevsk and Odessa and were coordinated by the existing Russian society of amateurs and world leaders. Similar observations were conducted by a collective of observers of the former Moscow society of amateur astronomers. Later work on meteor astronomy was carried out at the P. K. Shternberg State Astronomical Institute and at the Institute of Theoretical Geophysics of the Academy of Sciences USSR. Extensive visual observations of meteors were conducted also by members of the All-Union Astronomical and Geodesic Society.

As a result more than ten years of work attained serious successes. First of all, starting from the end of the 1920's and during the 1930's the method of visual observations of meteors was considerably improved and its errors investigated (E. Epik, 1921; V. A. Mal'tsev, V. V. Fedynskiy, and later I. S. Astapovich, 1958). Then a number of new meteor showers was discovered and catalogs of their radiants composed, and also showers already known at that time were studied in detail. For certain showers in 1934-1940 their orbital elements were definitized, the structure of the showers and the physical characteristics of meteors were studied: brightness, color, speed, height of breaking up, etc., the connections between showers and comets and the evolution of showers were studied, different dependences (for example, height on speed, length of apparent paths on distances to radiants and others) were found (N. N. Sytinskaya, V. V. Fedynskiy, I. S. Astapovich).

Much attention was given to the study of ionization traces of meteors, determination of directions and speed of their drift, and together with this – the study of physical properties of airstreams in the upper layers of the atmosphere (V. V. Fedynskiy, 1950). Dust trails of several bolides were studied also.

Toward the end of the 1930's with the help of telescope or binoculars observations of so-called telescopic meteors were begun, i.e., meteors of low brightness, invisible to the naked eye. Later telescopic meteors were observed especially intensively and are now being observed at the Astronomical Observatory of the Institute of Astrophysics of the Academy of Sciences of the Tadzhik Soviet Socialist Republic in Dushanbe.

Finally, in the 1930's photographic and photometric methods for observations of meteors were developed and used (N. N. Sytinskaya). In 1938 at the astronomical observatory in Dushanbe the first meteor patrol in the USSR was established under the leadership of Ye. N. Kramer, and the photography of meteors began, using cameras with shutters, which permitted determining the speed and deceleration of the meteoric particles.

One may assume that the 1940's finished the first period of the observations of meteors in our country. It is characterized mainly by observations conducted in considerable degree by amateur astronomers using the visual method. Along with this preparation was laid for more exact observations by photographic methods.

In 1945 began the second period in the observation of meteors. Even during the war (1942) a new center of meteoric observations was created in Ashkhabad (Institute of Physics and Geophysics of the Academy of Sciences of the Turkmen Soviet Socialist Republic). In Dushanbe and Ashkhabad began extensive observations of meteors by visual and photographic methods. The use of short-focused cameras with small dispersion began, making it possible to obtain spectrograms of meteors. Simultaneously a new radar method of meteor observations was introduced into practice; near Dushanbe a special

Photography of meteors. Obtained 14 August 1958 at the Astronomical Observatory of the Institute of Astrophysics, Academy of Sciences of the Tadzhik Soviet Socialist Republic (above — photograph obtained without shutter, at the bottom — with shutter).

station was built for radar observations. For the first time in Soviet Union the radar method was used in 1946 during observations of the Draconid meteor shower. As a result it was possible to trace the maximum of the shower, which was observed in bright daylight after the sun had risen. The radar method, founded on the

study of radio waves reflected from ionization trains of meteors and recorded by the photographic method in the form of curves, the so-called echo method, permits determining the distance to meteors, their speed and direction of motion.

The meteor patrol established at the observatory in Dushanbe was considerably improved, in 1953. In 1956 under Ye. N. Kramer a new, standard meteor patrol was created, of which there are staffs at Dushanbe, Odessa, Kiev, and Ashkhabad. In the 1950's the Institute of Applied Geophysics of the Academy of Sciences USSR began the investigation of penetration of meteor particles into the earth's atmosphere.

The basic result of the study of meteors in the second period was the creation of a physical theory of meteors. It is expounded in the monograph of B. Yu. Levin (1956). The physical theory permits presenting a general picture of the phenomena considering motion of meteor particles in the earth's atmosphere. This theory is based on analysis of two basic interacting processes — evaporation and deceleration of meteor particles. The monograph contained results of long investigations conducted at the Institute of the Physics of the Earth, Academy of Sciences USSR, on the quantity and distribution of meteor substance in interplanetary space. In 1957 a handbook was published for the photographic observation of meteors, composed by L. O. Katasev on the basis of cumulative experiment. In 1958 the monograph of I. S. Astapovich about meteors appeared, in which the author expounded the results of observations and study of meteors conducted mainly by himself during the period of three decades. In 1961 a new, considerably expanded instruction for visual and photographic observations of meteors and their treatment (I. T. Zotkin) was developed.

The beginning of the third period in the field of study of meteors coincides with the beginning of the International Geophysical Year (1957). This period is characterized by considerable expansion and improvement of the radar method of observing meteors. According to the program of the IGY radar observations of meteors were conducted

in astronomical observatories of the Odessa, Kazan and Kiev State Universities, at the Kharkov Polytechnical Institute, Tomsk Polytechnical Institute, Institute of Astrophysics of the Academy of Sciences of the Tadzhik Soviet Socialist Republic, at the Institute of Physics and Geophysics of the Academy of Sciences of the Turkmen Soviet Socialist Republic. This work permitted obtaining extensive information about meteors and about properties of the upper layers of the atmosphere. Success of the work was ensured in considerable degree by the fact that during the observations of meteors a whole complex of methods was used: visual, photographic (including photometric) and radar.

As a result a significant number of orbits of individual meteors and meteor showers was determined and their catalogs were composed; the structure of many meteor showers was investigated, for example the Quadrantids, Lyrids, Perseids, Draconids, Geminids and others; the connection of meteor showers with comets was studied and catalogs of cometary radiants was composed (Ye. N. Kramer, 1954; Ya. L. Al'pert and others, 1960; B. L. Kashcheyev, V. N. Lebedinets, 1961). Results of extensive investigation of meteors by the radar method, as also a description of the actual method, are contained in the recently published monograph of B. L. Kashcheyev and V. N. Lebedinets (1961). Also an important contribution was another monograph on the method and certain results of photographic investigations of meteors (P. B. Babadzhanov, Ye. N. Kramer, 1963).

Meteor stations created in the period of the International Geophysical Year at Vannousk (near Ashkhabad), Tripol'ye (under Kiev), Mayakakh (near Odessa), Savino (near Kharkov) and Simferopol are still successfully operating.

For coordination of work in the Soviet Union on meteors, and also for discussion of obtained results and the development of further directions in 1935, 1937 and 1939 three conferences were conducted on cometary and meteor astronomy. In 1937 at the Astronomical Council of the Academy of Sciences USSR the Commission on Comets and Meteors was created which is the coordinating center

of scientific work in the Soviet Union in the region of cometary and meteor astronomy. From 1951 to 1965 the commission conducted 11 plenary sessions. In 1956 publication of the nonperiodic "Bulletin of the Commission on Comets and Meteors" was started (as of 1964 nine issues were published).

At present in the Soviet Union the study of meteors is held in great esteem. Subjects on meteor astronomy are included in plans for scientific work of many astronomical and other scientific research establishments. This is explained by the fact that scientific interest toward meteor astronomy strongly increased in connection with the beginning of study of celestial bodies using artificial earth satellites and spaceships.

The study of meteors is not less important in the solution of many purely astronomical problems: structure and evolution of the solar system, processes of accretion and disintegration of the substance of this system. It is of great value also in the study of dust matter in the Galaxy. In geophysics meteors help to study physical properties of the terrestrial atmosphere; meteors render an essential influence on the state of the upper ionized layers of the atmosphere. The recent establishment of the existence of a dust medium in the environment of the earth increases the value of study of meteors for the problem of the motion of artificial earth satellites and interplanetary ships in interplanetary space.

Meteorites

Meteorites should be called remnants of space (meteoric) bodies, falling on the surface of the earth or some other planet or its satellite independently of the source of formation of these space bodies. It is necessary to exclude the fall of remnants of artificial bodies – artificial earth satellites, their rocket carriers, etc. The dropping of these objects to earth is accompanied by phenomena very similar to those which are observed when meteorites fall. However, such bodies cannot be considered meteorites.

Contemporary data permit us to allow the existence of at least three sources of formation of meteorites. The basic source is asteroids. Products of the destruction of asteroids, generated as a result of their collisions, constitute the usual meteorites, subdivided into iron, iron-stone, and stone.

Another source of meteorites can be the moon. Thus, there exists a hypothesis that tectites, small glass formations of unique form are fragments of the surface layer of the moon (D. O'Keefe and others, 1966). They are chipped off as a result of the blows of meteoric bodies and then fall to the earth. Passing at cosmic speeds through the terrestrial atmosphere and being subjected to heating, they are completely turned into remelted pieces of glass. There is also a hypothesis that stony meteorites are also fragments of the lunar surface (G. Yuri).

Finally, a third source is apparently comets. We can judge about this from results of study of the Tungus fall. The fall obviously was caused by the collision of a comet with the earth (see further). Due to the friable structure of the nuclei of comets and the presence in them of a considerable amount of volatile components in the frozen state (Levin, 1960; Fesenkov, 1964) the product of the destruction of cometary nuclei, forming during passage through the atmosphere of the earth, constitutes a finely dispersed substance (meteor dust) which scatters in the soil layer. The cometary origin certain researchers ascribe also to so-called carbonaceous chondrites (D. Wood).

The study of meteoric substance in all its states and manifestations, including meteorites, composes an independent region of science — meteoritics. One of the most important problems of meteoritics is the motion of meteoric bodies in interplanetary space and the earth's atmosphere. Another problem is the real composition, structure and physical properties of meteorites, isotope composition of separate elements and ages of meteorites. The solution to these problems has paramount value, on one hand, for establishing the conditions of formation of meteorites (both the components of their

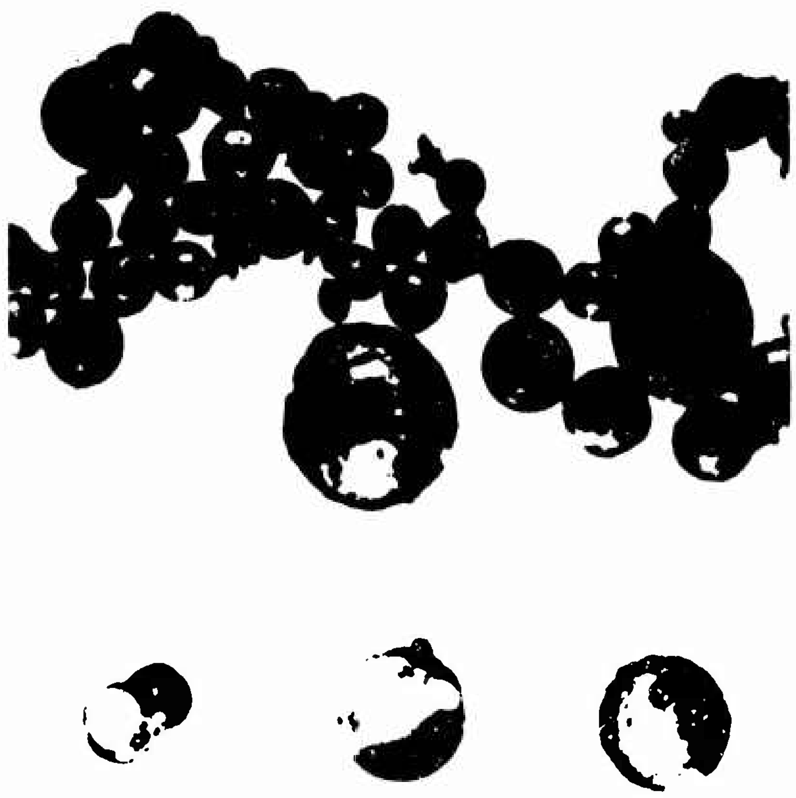
substance, and the meteorites themselves as independent space bodies), and on the other — for clarification of their role in the history of the development of the solar system. Therefore the study of meteorites is necessary for planetary cosmogony.

In tsarist Russia the study of meteorites occupied only individual scientists who were interested in small particular questions. A systematic collection of meteorites and information about the observation of their falls was not organized. Meteorites found their way to scientific establishments accidentally; many of them were lost to science, remaining in some individual's hands. There was no systematic study of the real composition of meteorites. Yes, and meteoritics at that time still was not fully established.

At the end of the 1950's and beginning of the 1960's the author proposed the determination of the contents of meteoritics as a special region of science, its direction and value (Ye. L. Krinov, 1960).

After the Great October Socialist Revolution the development of domestic meteoritics, as also the remaining divisions of science underwent a sudden change.

In 1921 at the initiative of Acad. V. I. Vernadskiy in the Mineralogic Museum of the Academy of Sciences USSR the Meteoritic Department was created, which he headed. In that same year the Soviet Government allocated funds for carrying out the first meteoritic expedition in our country, organized by the Academy of Sciences. Under the leadership of L. A. Kulik the expedition carried out much scientific work and delivered in 1922 to the Meteoritic Department new meteorites and numerous information about their falls. Because falls of meteorites occur suddenly and observations therefore are by accidental eyewitnesses, for more effective collection of information in the Meteoritic Department a network of voluntary correspondent-observers was organized from the number of amateur natural scientists. Special instructions (L. A. Kulik, Ye. L. Krinov) were issued as an aid.



Meteoric dust from region of Tungus fall. Upper photograph — magnetite pellets; lower photographs: left: — two joined pellets, magnetite and silicate; middle — silicate pellet with magnetite sticking to it; right — silicate pellet with magnetite in it; ×150.

In 1935 at the Academy of Sciences of the USSR a Commission of Meteorites was created under the chairmanship of Acad. A. Ye. Fersman, reorganized in 1939 into the presently existing Committee on Meteorites, and the Meteoritic Department was abolished. The chairman of the committee was Acad. V. I. Vernadskiy (1863-1945), and after his death (1945) up to the present — Acad. V. G. Fesenkov.

The Committee on Meteorites of the Academy of Sciences USSR is the central scientific establishment on meteoritics in our country. It is occupied with the collection, study and storage of meteorites, and also coordination of scientific investigation in the region of meteoritics in the Soviet Union.

The Committee on Meteorites conducts regular meteoritic conferences: from 1949 to 1964 there were 11 conferences. It publishes "Meteoritics," an irregular collection of articles; from 1941 to 1966 27 issues have been published, around 320 printer's sheets in overall volume.

In the Soviet Union a series of scientific monographs, handbooks,

catalogs and popular science books on meteoritics have been published, as a result of which the gap in scientific and popular science literature on meteoritics, existing up to the revolution, has been filled.

The population of our country takes an active participation in the collection of meteorites and in sending in reports about observed bolides — especially bright meteors (brighter than Venus in the period of its greatest brightness). One may see this from the following data: 1 January 1967 in our country 135 meteorites had been collected and preserved in various museums (every separate fall or finding is considered, which in every such case there can be several and even many separate meteorites). Of these up to the Great October Revolution, i.e., 140 years, counting from the moment the first meteorite (the Pallasite Iron Meteorite) reached the Academy of Sciences (Kunstkammer) in 1777, 80 meteorites had been found. Thus, on the average every two years in this period one meteorite was found. Meanwhile in the Soviet period, i.e., during the last 50 years, 55 meteorites were collected, i.e., on the average every year one new meteorite was found.

Here are the most interesting meteorites of those falling on the territory of our country and found after the October Revolution.

February 27, 1918, near Kashin (now Kalinin obl.) fell the large stony Kashin[1] meteorite (chondrite) weighing over 120 kg. During the several days before the meteorite was taken to Moscow it was the object of a veritable pilgrimage by the inhabitants of surrounding villages. Everyone tried to take a piece for himself: some from superstitious or religious considerations, and some simply for a remembrance. As a result the meteorite was severely cut up, which strongly damaged it from a scientific standpoint.

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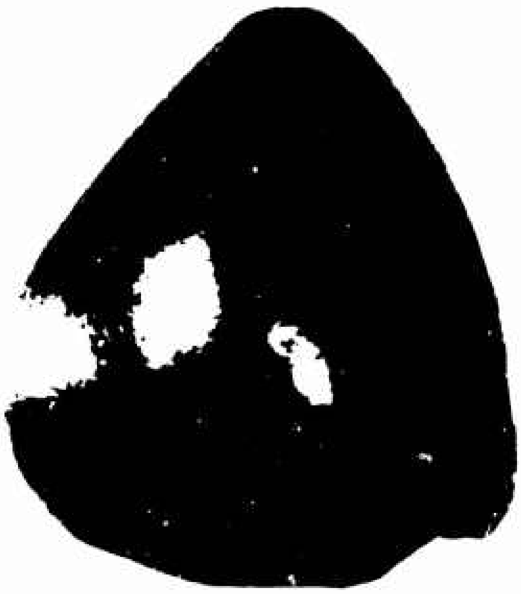
[1]A meteorite receives the name of the inhabited locality or geographic object nearest where it falls.

October 6 of the same year another stony meteorite (chondrite) fell — the Saratov meteorite. While moving in the atmosphere along a very flat trajectory, it split into several parts. Four individual specimens were found (total weight over 220 kg), falling over a territory nearly 120 km in length. This is the greatest area of the ellipse of scattering of all falls of meteor showers known in the world. A meteorite is very fragile and is distinguished by abundant chondrites (round formations on the average nearly 1 mm in diameter, dispersed in the basic mass of the meteorite).

April 20, 1930, in Orenburg obl. fell the very interesting Staroe Boriskino stony meteorite, belonging to a very rare type — carbonaceous chondrite. Two specimens with a total weight of 1.34 kg were found. At present little more than twenty carbonaceous chondrites are known (out of approximately 1700 meteorites), found over the whole earth and belonging to various classes and types. The special interest toward carbonaceous chondrites is because they contain water of crystallization and organic substance; however, the last one has undoubtedly an abiogenic origin.

May 26, 1932, in Novosibirsk obl. fell the small stone (chondrites) Kuznets meteorite shower. More than 10 specimens were collected, weighing nearly 7 kg in all. The stones possess interesting morphologic properties. Thus, for example, two entire specimens, falling around 3 km from each other and covered by a fusion crust on all sides, stick tightly to one another when they are put together. It is very clear that the surfaces of contact of both specimens have characteristic unevennesses of the split, although they are covered by crust. Such surfaces are called surfaces of the second kind and will be formed when the meteorite splits near the delay region. On the example of the Kuznets meteorite the mechanisms of splitting and loss of masses of meteoric bodies in the atmosphere of the earth during their motion at cosmic speeds are visually traced.

The very interesting Repeyev Khutor iron meteorite (octahedronite) fell 8 August 1933 in Astrakhan' obl. It weights 12.35 kg, differs



The Repeyev Khutor iron meteorite (weight 12.35 kg), having the shape of a flattened octahedron.

by its regular form, which is close to an octahedron. It is true that during motion in atmosphere the form of the meteorite endured a strong change: from it split off a part equal to approximately 1/3 the initial volume, and as a result of fusion during rotation the edges and vertices of the octahedron were dulled and the meteorite obtained a flattened shape, more reminiscent of a cone.

October 2 of the same year in Kurgan obl. fell an interesting stony meteorite shower of rare type (achondrite-orbit). The found specimens (approximately ten) of total weight 2.393 kg are almost wholly formed from crystal fragments of snow-white enstatite and are covered by a semitransparent glasslike fusion crust.

Finally, December 26 of the same year in Ivanov obl. fell the rather abundant Pervomaiskiy Poselok stony meteorite shower (chondrite). The location of the fall of this shower was determined instrumentally on the basis of eyewitness accounts of the apparent path of the meteorite (bolide) in the heavens. Altogether 95 specimens totalling 48.98 kg were collected. It is interesting that some specimens consist of a gray substance, and others are wholly a black substance; some have been found consisting simultaneously of gray and black substance with a clear-cut line between them.

April 2, 1936, in Zaporozh obl. the Yurtuk stony meteorite (achondrite-govardite) fell. Only several stones with a total weight of around 1.5 kg could be collected. The biggest stone pierced the tile roof of a home and fell into the attic, where it was found. Such cases of meteorites hitting a structure are very rare.

September 13, 1937, in the Tatar ASSR fell the large stony Kainsaz meteorite (black chondrite). Fifteen samples totalling around 210 kg were collected. The biggest stone weighed 102.5 kg, and the smallest (the size of a forest nut), which fell around 27 km from the biggest, was only 7 g.

January 11, 1938, in Orenburg obl. on frozen, barren snow fell the small Lavrent'yevka stony meteorite (chondrite), weighing 0.8 kg, which spun around when it hit the ground. Obviously, the meteorite still had rotational motion as well as forward as it moved through the atmosphere. As a result of this it had absolutely smooth surfaces with a complete absence of "regmaglipts" [Translator's Note: регмаглиптов = regmaglipt — a Russian word meaning the characteristic deepenings on the surface of meteorites, formed as a result of the swirling motion of the earth's atmosphere on the surface layer of the meteorites as they move through space at cosmic speeds. Dimensions: from a few millimeters to several centimeters] (pits resembling fingerprints in soft clay or plasticine), so characteristic and usual for meteorites; they are formed as a result of turbulent eddies of the atmosphere in the shock wave adjacent to the meteoric body.

May 23 of the same year a small stony meteorite (chondrite) fell at Pavlogard, Kazakh Soviet Socialist Republic. Two stones were found. One of them, weighing around 120 g. fell in the city area; the other, weighing around 300 g fell in Lenin Street near passing inhabitants and was still warm when picked up.

Finally, in that same year, on the night of October 9, in Donets obl. the Zhovtnevyy Khutor big stony meteorite shower (chondrite) fell. Thirteen specimens weighing a total of nearly 107 kg

were collected. The biggest stone weighed 32 kg. Two specimens, weighing around 19 and 13 kg, falling approximately 1.5 km from one another, coincided with each other with composition of the second type of surfaces. Such surfaces are also observed on other specimens of this meteorite shower. This indicates that some of the falling stones were not found.

June 23, 1939, in Sumy obl. fell the small Chervonyy Kut meteorite, weighing 1.7 kg and belonging to the rare eucrite type.

January 21, 1946 in Odessa obl. fell the rather heavy Crimean stony meteorite shower (chondrite). Seventy-seven specimens weighing a total of around 40 kg were collected. It is interesting that the stones were gathered over a period of ten years and always during the spring work in fields, gardens and kitchen gardens.

June 11, 1949, in Chelyabinsk obl. fell the great Kunashak stony meteorite shower (chondrite). Around 20 specimens totalling over 200 kg were found. The biggest stones weighed 120, 40 and 36 kg respectively. The biggest stone formed a pit 2 m deep and across and split into several big pieces and a multitude of fragments. One of the smallest stones, weighing 358 g, pierced the roofing of a grain dryer, damaged the rafters and fell to the floor. Some stones in this meteorite shower were formed from a gray, others from a black substance, and still others from gray and black together.

March 6, 1954, the small Nicol stony meteorite (chondrite) fell 34 km from Moscow. This meteorite differs by its very fragile composition and crumbles in the hand.

In 1955 in Minsk obl. the big Cressl iron meteorite (hexahedronite) weighing around 300 kg accidentally was discovered.

The very interesting Yardymlin iron meteorite (octahedronite) fell 24 November 1959 in the Azerbaydzhan Soviet Socialist Republic. It was possible to find six specimens totalling 152 kg; of these

the biggest weighed around 128 kg. This is the fifth recorded iron meteorite fall on the territory of our country to be observed by eyewitnesses.[1]

In 1960 on the outskirts of Odessa the small Odessa stony meteorite (chondrite), weighing 1.926 g, and interesting because of its oriented shape (round loaf-like) was found.

In 1962 in the summer in Chitin c. .. the first iron-stone meteorite of the rare mesosiderite type in our country was discovered. It weighed 110 kg and is called the Budulan meteorite.

The last meteorite fall in our country happened 18 December 1963 on the ice of Lake Zaysan (Kazakh Soviet Socialist Republic). Only one 463 g specimen was found. However, judging by its polyhedral form and other morphologic peculiarities, we can say confidently that a multitude of meteorites fell here.

The last two accidental meteorite findings in our country were in June 1964 in the Komi Autonomous Soviet Socialist Republic, where a small, but very interesting stony meteorite of the rare achondrite type was found (weight 327 g), called the Pomozdino meteorite. This meteorite differs in that only separate sections are covered by fusion crust although the meteorite is one piece. On bare sections of the surface under 15-30 times magnification spray and hardening drops and balls and separate streams can be seen clearly.

Another find was made in August 1965 in the Perm obl. The 2 kg Severnyy Kolchim stony meteorite (chondrite) was found.

In the study of meteorite falls on the earth, Soviet scientists in the 1940's and mainly in the 1950's and 1960's carried out a

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[1]Iron meteorites fall considerably less frequently than stone: for every iron fall there are on the average 15 stone falls.

number of investigations, and obtained approximate data about the atmospheric trajectories of certain meteorites (I. S. Astapovich, I. T. Zotkin, Ye. L. Krinov, V. A. Bronshten and others). It is necessary to isolate three large studies: the Tungus fall, the Sikhote-Alin' iron meteorite shower and, finally, the meteorite craters on the island of Saarma in the Estonian Soviet Socialist Republic.

As is known, the Tungus fall happened in the morning of 30 June 1908 in the now Evenkiyskiy National Okrug. It was accompanied by flight across the sky of a bright fireball above the enormous territory of Central Siberia from southeast to northwest, strong explosions and seismic phenomena. Furthermore, for several nights after the fall, anomalous optical phenomena were observed in the earth's atmosphere.

To study the Tungus fall the Academy of Sciences of the USSR under L. A. Kulik directed three consecutive expeditions: in 1927, 1928 and 1929-1930. During the first expedition Kulik discovered a radial tree fall in the impact area. At that time he considered that the fall was caused by a swarm of meteorites, of which the biggest exploded upon impact with the ground, forming a funnel. Kulik considered these funnels to be those numerous round swamps tens of meters in diameter, which he discovered in the central part of the fallen trees. In 1938-1939 aerial photographs were taken of the central part. By this time Kulik rejected the initial assumption about the meteoritic origin of swamps and instead decided that the fall and explosion of the meteorite occurred at the so-called Southern Swamp, 3-5 km in diameter. On the bottom of this swamp he unsuccessfully tried to detect the trails of meteoritic craters (L. A. Kulik, 1939). Survey of data on the Tungus fall collected by Kulik during the study was published by this author in 1949.

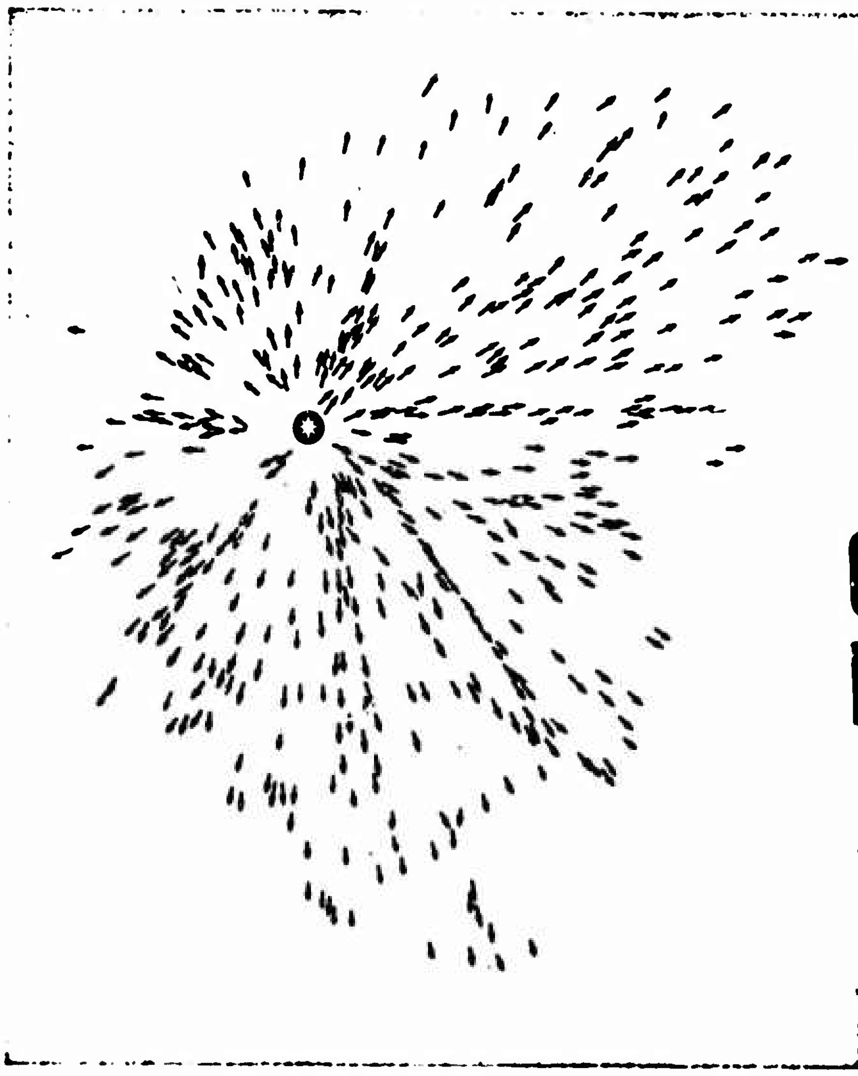
New investigations of the Tungus fall were begun after the death of L. A. Kulik, who died at the front in the Great Patriotic War in 1942. In 1958, 1961 and 1962 the Committee on Meteorites

of the Academy of Sciences USSR jointly with the Institute of Geochemistry and Analytic Chemistry of the Academy of Sciences USSR made three new expeditions. Dozens of specialists in a number of areas from different scientific establishments took part.

The expeditions established that the explosion of the Tungus body happened not on impact with the ground, but several kilometers in the air. The round swamp pits, just as the Southern Swamp, have a natural origin and are connected with presence of permafrost. The burn caused by the Tungus fall has a different character than described by Kulik (and the author). It is damage of the cambium layer (located between crust and wood and serves as formative tissue) and is observed on cuts of growing trees which survived the catastrophe. The burned ends of the branches and trunks, according to Kulik caused by the burn induced by the Tungus fall, in reality are explained by an ordinary forest fire. The expeditions thoroughly studied the whole region of the radial tree fall and composed a map of its exact location. In the soil layer was found disperse cosmic substance, consisting of magnetite, silicate and mixed balls and other spheroidal particles, making up the product of destruction of the Tungus body.

The dependence of concentration of these particles in the soil on the direction of motion of the Tungus body and wind blowing at the time of fall was established (O. A. Kirov, 1958; K. P. Florenskiy, 1961; I. T. Zotkin, 1961; V. G. Fesenkov, 1961; P. I. Kurbatskiy, 1964, and others).

On the basis of all collected data on the Tungus fall it was concluded that the most probable is the hypothesis about the cometary nature of the Tungus body. In other words, the Tungus fall was caused by a collision of the earth with a small comet. Therefore study of the Tungus fall became still more important, inasmuch as it is the first and as yet only phenomenon of this kind, observed by eyewitnesses and leaving numerous and various trails on the earth's surface. Study of the Tungus fall is still unfinished and continues in the Committee on Meteorites, the Institute of Geochemistry and Analytic Chemistry and other scientific establishments.



Map of radial tree fall in region of Tungus fall.

It is necessary to say that in recent years study of the Tungus fall has attracted the exceptional interest of a group of young scientists, graduate and nongraduate students from Tomsk. Initially this group of enthusiasts called the KSE (Overall Amateur Expedition) by community effort made an independent study of the fall under the general leadership of G. F. Plekhanov. Later many participants of the group joined expeditions of the Committee on Meteorites and the Institute of Geochemistry and Analytic Chemistry. They introduced an essential contribution to the studies made by these expeditions (G. F. Plekhanov and others, 1963).

The Sikhote-Alin' iron meteorite shower fell in the western spurs of Sikhote-Alin' 12 February 1957 at 0038 hours universal time or at 1038 hours Vladivostok time (V. G. Fesenkov, Ye. L. Krinov

and others, 1959, 1963). The meteorite shower was observed by numerous eyewitnesses over a territory more than 400 km in radius. The shower dispersed over an area of 1.6 km^2. From 1947 to 1950 the Committee on Meteorites sent a yearly expedition to the impact area to study the fall area and collect the meteoritic substance. As a result of the work of all four expeditions, working altogether 19 months, an enormous amount of scientific material was collected and an exact map of the fall was composed on the basis of special aerial photography — filming the fall area.

This map contains 375 fall points, distributed in the following way:

Funnels from 0.5 to 26.5 m..........122

Holes less than 0.5 m in diameter....78

Places where small specimens fell, weighing from 2 kg and less (surface scattering).............175

In all 78 holes and 113 funnels were uncovered and the whole and split meteorites located in them were extracted and delivered to the Committee on Meteorites.

The collected meteoritic substance is distributed in the following way:

1. Whole individual specimens weighing from fractions of a gram to 1745 kg — 313 specimens, total weight 11839.7 kg.

2. Individual specimens cleaved and split into large parts — total number 27, consisting of 42 parts 6167.2 kg in total weight.

3. Great and fine fragments of split individual specimens — total number 79?7 and total weight 5201.5 kg.

A total of 23208.4 kg of meteoritic substance was collected.

According to calculations made on the basis of consideration of size and number of all funnels and holes and the established

Biggest whole individual specimen of the Sikhote-Alin' iron meteorite shower, weight 1745 kg.

Typical fragment of an individual specimen of the Sikhote-Alin' meteorite shower.

linear dependence of hole and funnel size on meteorite size (approximately), the total mass of all falling meteoritic substance was determined, composing around 70 t. Thus, the total weight of the remaining uncollected meteoritic substance was determined as approximately 47-50 t.

On many individual specimens are observed various phenomena of pulverizing (spraying): hardening drops, balls, streams, fine

calibration lines, etc. They visually show the melting of the surface layer of meteorites, occurring as they move through the atmosphere at cosmic speed.

In soil was revealed disperse substance of three forms: meteoritic dust, the product of the spliting of big meteorites upon impact with the ground and consisting of acute-angled particles — the smallest meteorite fragments; meteor dust, consisting of balls, hollow bulbs and other spheroidal particles of magnetite composition — products of the destruction (melting and spraying in the atmosphere during motion at cosmic speed) of meteorites (see Fig. on p. 171); micrometeorites — the smallest meteorite fragments, separating upon splitting in the atmosphere and then fusing again. Micrometeorites are from tenths of a millimeter in size and weigh from thousandths to hundredths of a gram.

The following data about the real composition of the meteorite shower were obtained. Mineral composition (in percent by weight): nickel iron (kamacite, taenite and plessite) — 98.34, shreibersite — 1.36, troilite and chromite — 0.30; total chemical composition of meteoritic substance (in percent by weight): Fe = 93.29, Ni = 5.94, Co = 0.38, Cu = 0.03, S = 0.23, P = 0.46; specific gravity 7.78 g/cm^3. Structure of the meteorite is characterized by mutual location of kamacite balls at angles corresponding to octahedronite composition. Thus, meteorite belongs to the very rough structural octahedronites.

On the island of Saarma a remarkable group of seven craters, called Kaali, has long been well-known. For a long time the origin of these craters remained a puzzle. The main crater, filled with water, has a diameter of 110 m and depth of 16 m. The remaining craters are dry, with diameters from 11 to 50 m. These craters were studied by the mining engineer I. A. Reinwald who in 1937 proved their meteoritic origin. He observed in them fragments of iron meteorite and showed the particular structure of the craters, characteristic for meteorite craters. From 1955 on the craters have been studied by the Estonian geologist A. O. Aaloe under the leadership of Acad. K. K. Orvik (A. O. Aaloe, 1963).

Structure of fusion crust observed on the surface of one specimen of the Sikhote-Alin' meteorite shower.

In the Soviet Union there has been wide theoretical research on conditions of the fall of crater-forming meteorites and the formation of meteorite craters (V. V. Fedynskiy, G. I. Pokrovskiy, 1964; K. P. Stanyukovich, V. A. Bronshten, 1961, and others).

At present in the Committee on Meteorites special automatic camera is being designed for photographing the bright bolides and a new method is being developed for obtaining from photographs exact data about trajectories and orbits. Similar observations are already being conducted systematically in Czechoslovakia and the United States.

During the last three decades the author has systematically studied morphology of meteorites. As a result it has been established that as the meteoric body travels in the atmosphere at cosmic speed, it is subjected to two main forms of destruction: splitting and melting. As a result of splitting, usually not single meteorites drop to the ground, but meteorite showers, and as a result of melting in the earth's atmosphere meteor dust — falls — hardening drop-balls, blown from the melting surfaces of meteoric bodies. A classification of the surface structure of the fusion crust has been developed. Morphological study of meteorites showed that as they move through the atmosphere, meteoric bodies lose a relatively small part of their initial mass and that in interplanetary space defined types of meteoric bodies are not shapeless fragments, but have regular forms of polyhedrons corresponding to their internal structure.

Soviet researchers attained considerable successes in the study of composition, structure and physical properties of meteorites, and also in showing defined regularities in composition and their structure.

Even in the 1930's and at the very beginning of the 1940's the mineral and chemical composition of meteorites was being studied. This marked the start of systematic study of the composition and structure of meteorites, and obtaining new data, corresponding in accuracy to the contemporary level of development of science (P. N. Chirvinskiy, B. M. Kupletskiy, L. S. Selivanov and others).

After the war Acad. A. N. Zavaritskiy in the Committee on Meteorites of the Academy of Sciences USSR set up systematic work on study of the mineral composition and structure of meteorites.

As a result for the first time in the history of existence of the collection of meteorites of the Academy of Sciences of the USSR it was scientifically described. Petrographic study of meteorites continues at present under the leadership of L. G. Kvash.

During the last decade the Committee on Meteorites conducted systematic analyses of the chemical composition of meteorites of various classes and types (A. A. Yavnel', 1958; M. I. D'yakonov, V. Ya. Kharitonov, 1960, 1961); B. Yu. Levin with his colleagues figured the average composition of meteorites (1956).

At the Radium Institute, in the Laboratory of Geology of the Pre-Cambrian period and in the Institute of Geochemistry and Analytic Chemistry of the Academy of Sciences of the USSR I. Ye. Starik and others (1960) carried out extensive investigations of the isotope composition of separate chemical elements and worked on determination of the age of meteorites. It is necessary to note that the Soviet scientist E. K. Gerline (1956) was the first to use successfully in determining the age of meteorites the sodium-argon method; the maximum age of meteorites turned out to be 4-4.5 billion years.

Investigations of the isotope composition at present are being successfully carried out in the Institute of Geochemistry and Analytic chemistry of the Academy of Sciences, USSR (A. P. Vinogradov, A. K. Lavrukhin, I. K. Zadorozhnyy and others, 1960, 1964).

Meteoritic and meteoric (balls) dust. (Extracted from the soil in the impact area of the Sikhote-Alin' iron meteorite shower. Around 40 times magnification.

GRAPHIC NOT REPRODUCIBLE

It is necessary to say that study of the composition of meteorites, including isotope composition of separate elements, the

investigation of regular bonds in meteorites, determination of their age and other questions at present have taken on a wide range and are joined by many researchers in a number of countries, especially in the United States, FRG, Switzerland, etc.

Accumulation of new, definitized real data about composition and structures of meteorites and use of data published in foreign scientific literature, permitted Soviet researchers to generalize all material, to show regular bonds in meteorites and to solve the problem about the conditions of their formation. As a result new data have been obtained about the cosmic abundance of chemical elements, and convincing evidence has been found that meteorites are fragments of many space bodies (asteroids), and not one great planet, as was assumed earlier (V. Yu. Levin, A. A. Yavnel').

In recent years our country has seen even more expansion of new directions in meteoritics. In the Institute of Geochemistry and Analytic Chemistry of the Academy of Sciences, USSR, from 1960 the nature of organic substance present in carbonaceous meteorites (chondrites) has been studied (G. P. Vdovykin and others, 1964). Starting from 1958 the physical properties of meteorites have been studied at the Institute of Geology of the Academy of Sciences, Ukrainian SSR (K. N. Alekseyev and others, 1958). In 1963 study of the magnetic properties of meteorites was started at the Leningrad division of the Institute of Terrestrial Magnetism, Ionosphere and Propagation of Radio Waves of the Academy of Sciences, USSR (Ye. G. Gus'kov, 1963). Somewhat earlier roentgenographic study of the separate minerals of meteorites was started at the Leningrad Museum of Mining (V. I. Mikheyev, I. V. Mikheyev, V. D. Kolomenskiy, 1963).

Finally, recently attention was allotted also to the study of tectites, which until now have never been found in the Soviet Union (G. G. Vorob'yev, 1960).

In conclusion one should say that past and continuing studies in the Soviet Union in the region of meteor astronomy and meteoritics

have obtained a wide scope and embrace practically all divisions of the regions of science we have mentioned. Therefore we can say confidently that in the region of meteor astronomy and meteoritics our country holds firmly one of the first positions in the world.

SUN

Although our sun is an ordinary star, this is the only star for which detailed study and localization of processes on its surface is possible, connected with the proximity of sun to earth and, consequently, with the brightness and angular dimensions of the sun. For all other stars except the sun our information is greatly "general": we obtain it, as it were, from the star as a whole, although in reality the values can pertain only to a limited section of its surface. Thus, for example, we know that stars have magnetic fields of up to 10 kg and more, but if they, just as in the case of the sun, are concentrated in spots occupying not more than 1/1000 of the whole surface of the star, then the actual magnetic fields should considerably (by two-three orders) exceed the observed. In other words, if the sun is removed to stellar distances from the earth, then we would not see the magnetic fields on it at all, since they are concentrated on a small area (in spots) which introduces an insignificant share to the radiation of the whole star.

The possibility of detailed investigation of the sun played a huge role in the development of nuclear physics. Studying the sources of solar energy, physicists for the first time encountered the idea of thermonuclear fusion. But only now have they been able to check this idea experimentally. In the United States recently the first attempts have been made to study the neutrino flux from the sun with the help of the neutrino telescope (some of the synthesis reactions of helium from hydrogen assumed inside the sun are

accompanied by abundant separation of neutrinos). The sun is the generator of particles of high energies, including cosmic rays; during strong flares on its surface not infrequently there appear protons with high energy – from several hundred keV to hundreds of MeV, but for the strongest flares a generation of cosmic rays was noted with energy to 10^{12} eV. Not only flares and other nonstationary processes, but also the whole chromosphere and corona of the sun generate powerful X- and ultraviolet radiation in different ranges of waves. Furthermore, the sun generates radio waves from several millimeters to tens of meters in length (see the section "Radio Astronomy").

Besides particle fluxes with speeds from several hundred to several thousand kilometers per second, outgoing from separate, so-called active regions, the sun is a source of continuous rarefied particle flux, passing from its surface – the so-called "solar wind," "blowing" with speeds of several hundres of kilometers per second and filling the interplanetary space surrounding the sun by a gigantic "superatomosphere" as it were. Therefore it is possible to say that we live as if in the atmosphere of the sun. Different radiations and processes on its surface, as are now clarified, render an essential influence on the earth and on the practical activity of man. They create favorable or unfavorable conditions of propagation of radio waves in the atmosphere of the earth, i.e., determine conditions of radio communications, change conditions of radar visibility during noise storms in radio emission of the sun, conditions magnetic storms and aurora polaris on the earth, and outside the atmosphere during solar falres, (generating cosmic rays). There appears a level of penetrating radiation which presents a serious radiation hazard for astronauts and any living beings in the cosmos. All these lead-in remarks we premised only to illustrate the exceptional importance of investigations of the sun not only from a purely scientific and cognitive, but also from a purely practical point of view.

Investigations of the sun, including spectrophotometric methods, even at the end of past century had been started in our country by the outstanding Russian astrophysicist A. A. Belopol'skiy (1854-1934).

As it is known, the activity of the sun changes over an 11-year period, but the cause of this cyclic recurrence is not well-known. In the later years of his life, by means of very thorough measurements of the rotation of the sun, A. A. Belopl'skiy tried to clarify whether or not analogous cyclical changes in the speed of its rotation connected periodicity of sunspot activity with changes of rotation of the sun. He could not find a definite answer to this question (these investigations were not continued), but nonetheless he obtained very valuable data on the dependence of the speed of rotation of the substance of the sun on heliographic width.

At the same time, at Pulkovo, Ye. Ya. Perepelkin (1906-1937) in 1928 started detailed spectral investigations of prominences and after 10 years (from 1933 together with V. P. Vyazanitsynym) had obtained much scientific material, allowing new essential conclusions concerning the physics of the sun. Subsequently investigations in this most important region, reflecting general tendencies in world science of the XXth century, have obtained an ever more collective character, which first appeared in the observation of solar eclipses. But their present effective character was achieved in postwar years. The great achievements in the technology of solar investigations had a decisive value.

Equipping the Soviet astronomy with new tools - not only foreign, but also domestic - began in the 1920's to 1930's. After the Great Patriotic War large solar telescopes were put into operation: the horizontal telescope of N. G. Ponomarev's system at Pulkovo and the tower solar telescope in the new astrophysical observatory in the mountainous Crimea (settlement Naychnyy), allowing study of the solar spectrum at its highest (on a contemporary level) dispersive and resolving power. For these investigations the development of method and manufacture of high-quality domestic diffraction gratings (F. M. Gerasimov) was important. In 1948-1951 the method of manufacture was developed and then narrow-band interference-polarization filters were made for observation (in particular, for cinematography) of the sun in rays of the hydrogen H_α line (A. B. Gil'varg, A. B. Severnyy, 1948; S. B. Ioffe, 1950). Magnetographs for photoelectrical

measurements of magnetic fields on the sun are successfully used.

An essential achievement of the postwar period of development of investigations of the sun was the creation of a wide network of stations in the solar patrol, embracing the range of longitudes from Vladivostok to the western boundaries of the USSR. The presence of such a network of stations, equipped with standard equipment for photographing the sun and monchromatic observations of it in H_α rays, permitted ensuring "patrol" observation of solar activity during more than half of the twenty-four hour period, in particular it ensured obtaining detailed information on all of the past processes on the sun, which are frequently connected with many geophysical effects. Especially valuable was information from the solar patrol during the International Geophysical Year.

A considerable part of investigations in the region of the physics of the sun is concentrated in the Crimean Astrophysical Observatory, AN SSSR, where a large collective works on the problems of heliophysics. An important center of investigation of the sun continues to be Pulkovo Observatory, the southern base of which is the mountain station under Kislovodsk. There extensive work is being conducted — systematic observations of the solar corona outside eclipses (M. N. Gnevyshev, R. S. Gnevyshev and others). Heliophysical observations are conducted also on the alpine solar station near Alma Ata. Solar installations are in Moscow (GAISH and IZMIRAN), Kiev, Tashkent, in Azerbaydzhan; recently the AMZMI (Irkutsk) solar telescope began operation.

One of the most characteristic features of the development of the physics of the sun in our country after the passing of 50 years was the many-sided study (basically spectroscopic, and later cinematographic methods) of physical processes on sun, which appear in active regions on the sun and are the basis of flares, prominences, facula, etc. Abroad in the physics of the sun investigations of the physical state of the solar atmosphere as a whole carried great weight. Such a characteristic partly is conditional, since both here and there an essential contribution in both directions was made. Started even in the 1930's at Pulkovo by Ye. Ya. Perepelkin,

spectroscopic investigations of active regions on the sun and the and the chromosphere (that part of the atmosphere of the sun where emission lines appear) at the same time were successfully continued and developed by O. A. Mel'nikov and V. P. Vyazanitsyn (in reference to the chromosphere and prominences).

Tower solar telescope of Crimean Astrophysical Observatory, AN SSSR. Tower of telescope.

Thus, they first established the presence of high speeds of disordered motions of atoms, considerably exceeding the speeds of their thermal motion – "turbulent" speeds – without which it is impossible to explain the observed large width of emission spectral lines of the chromosphere and prominences, especially in the case of lines of metals. In particular, V. P. Vyazanitsyn in 1947 first obtained

Tower solar telescope of Crimean Astrophysical Observatory, AN SSSR. Caelostat installation, directing rays of sun downwards into the spectrograph and spectroheliograph.

reliable data about temperature, density of neutral atoms and electrons in prominences, showed the important role of radiation from beneath the sun in the excitation of the atoms of prominences (this last conclusion has been confirmed recently in works of Kiev astrophysicists — N. A. Yakovkin and others). The same methods, applied in the 1950's by the Pulkovo astrophysicists to the solar chromosphere as a whole, permitted showing not only the high speeds of chaotic motions of gases, but also the growth of turbulent speed with height in the chromosphere.

A second distinctive line of Soviet heliophysics is greater attention to the fine structure of the solar atmosphere than to its average macroscopic characteristics. Thus Ye. Ya. Perepelkin even in the 1930's tried to explain the solar chromosphere as an accumulation of a multitude of fine lines — prominences, and V. A. Krat (1958) with his colleagues on the basis of study of Fraunkofer (dark) and emission chromospheric lines in the spectrum of the sun developed an idea about the chromosphere, which in his opinion, consists of hot and cold lines — prominences. The fact is that analysis of the contours of the spectral lines of different atoms led to various physical parameters (temperature, density and others). As V. A. Krat, T. V. Krat (1957) and V. M. Sobolev (1961) showed, this difficulty can be removed if one considers that optimum conditions for the glow of different atoms and ions of various elements are unequal, but then there inevitably follows the conclusion concerning the "coexistance" of different conditions in the chromosphere — hot and cold regions.

Until recently the progress of theoretical study of the photosphere was held back by the absence of exact contours of the Fraunhofer lines. In 1960 at the Pulkovo Observatory V. N. Karpinskiy introduced a double diffraction monochromator with photoelectrical spectrum registration, having a series of advantages as compared to other instruments of high resolving power. On this monochromator in 1963 B. G. Babiy and others conducted important work on study of the asymmetry of Fraunhofer lines. These investigations in particular showed that the existing model of photosphere with heterogeneities of temperature of the order of 1000° could not explain different forms of the contours of lines, or give the correct order of magnitude of

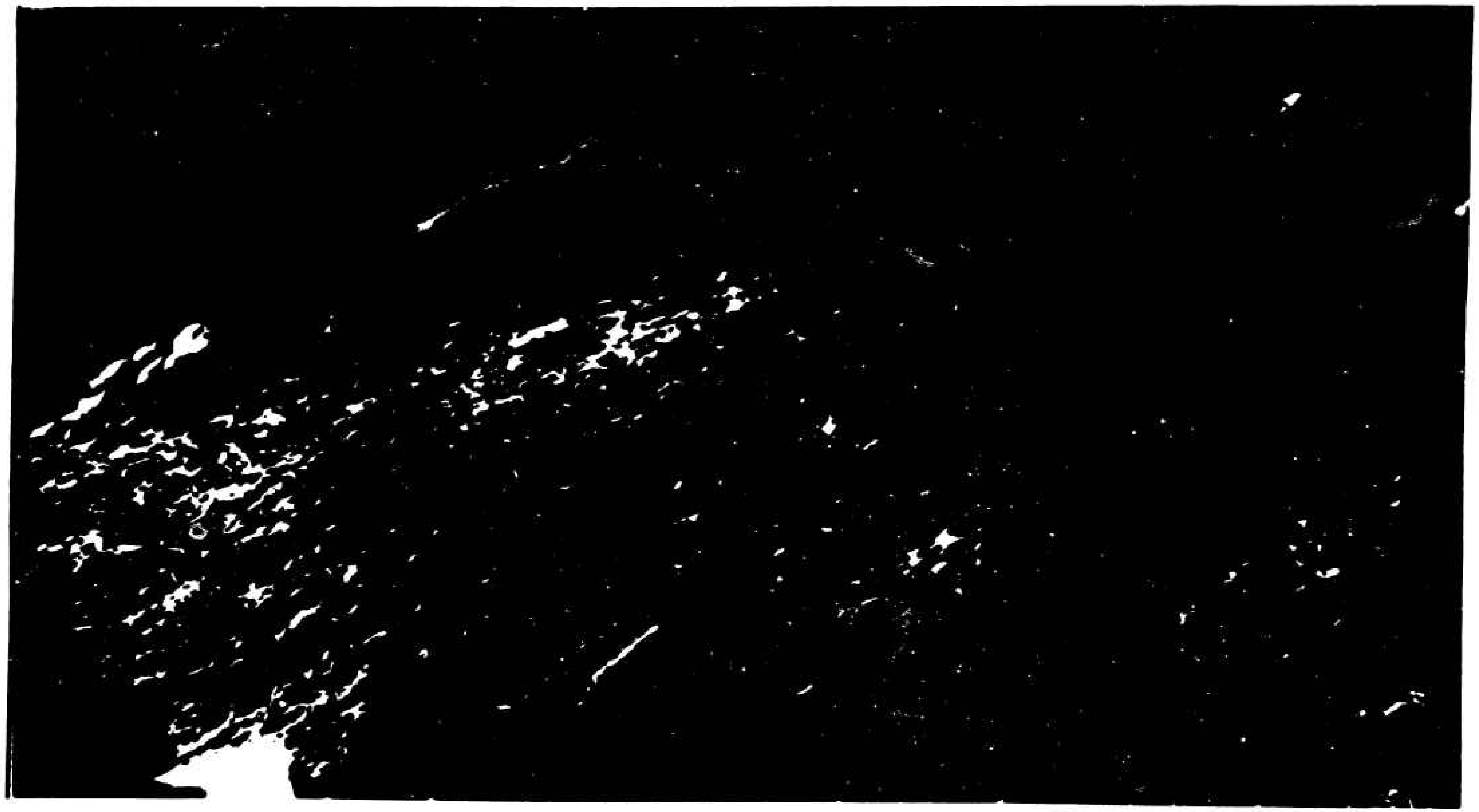
'he eclipse coronagraph of the Crimean Astrophysical Observatory, for cinematography of processes on the sun in rays of the ydrogen.

Fine structure of solar chromosphere in the hydrogen H_{α} line. Photograph taken 24 June 1962 on the spectroheliograph of the Crimean Astrophysical Observatory.

their asymmetry. Correct explanation of contours requires temperature heterogeneities of not more than 150-200°, approximately identical on all depths of the atmosphere.

Frequent intensification of the glow of green (λ 5303) and red (λ 6375) lines in the spectrum of the solar corona[1] in regions occupied by prominences also testifies to the unique "symbiosis" of a comparatively cold formation, which is a prominence with hot matter of the corona (kinetic temperature of which reaches 1.4 million degrees, see p. 205). On the sun is a unique fine structure of states, making possible the "coexistence" of very small volumes, where plasma is in strongly distinguished states. The fact of the existence of a comparatively cold chromosphere and prominences (temperature not

[1]So-called coronal lines, appearing during transitions between sublevels of the ground state of repeatedly ionized atoms: thirteen- and tenfold ionized atoms of iron.



Fragment of the lunar surface panorama, first obtained by the "Luna-9" station.

higher than 10,000°) surrounding the corona with a temperature exceeding 1 million degrees is one of the most striking in the physics of the sun. In connection with this it is interesting to note the weak glow of the cold component of the corona (helium D_3 line) observed in 1954-1955 by M. N. Gnevyshev and R. S. Gnevysheva as if it were "interspersed" in it at rather great distances from the edge of the sun – an effect lasting for days and coinciding with the intensification of monochromatic emission of the corona.

A study of physical conditions in the corona by observations of the green and red coronal lines was made also at Pulkova by I. A. Prokof'yev (1960-1961) using his invention, a coronagraph with optical circuit, different from the coronagraph of Leo. In particular, he found that expansion of contours of coronal lines in active regions of the corona is determined not so much by an increase of temperature as by an increase of turbulent speed.

The layer of solar atmosphere responsible for emission of a continuous spectrum – the photosphere – has a granular structure, as was shown by the brilliant photographs of P. Zh. S. Zhansen and A. P. Ganskiy, made already at the beginning of our century. This thin granular structure in 1954-1956 was studied at the Pulkovo Observatory by V. A. Krat with his colleagues (lifetime of elements of granulation, speed and character of motions were determined). Light granules are the places where the convection currents rising from the depths of the sun exit; their further cooling and sinking leads to the formation of dark intervals. Thus, the lower part of the photosphere strictly speaking also consists of two components – hotter, rising streams and colder, sinking streams. The transverse dimensions of these streams according to V. A. Krat are very small (not more than 700 km) and in a number of cases are possibly less than the resolving power of contemporary solar telescopes; granule lifetime is near 2 minutes.

Study of speeds of gas in granules and over them led to the conclusion that the main role here is played by sound and gravity waves, forming as a result of convection. In the upper layers of the atmosphere of the sun convection motion gradually fades, being turned into disorderly, turbulent motion, which in turn hampers

convection. Alternating thickening and rarefactions with such motions creates sound noise due to the fluctuations of density. Absorption of these noises in the photosphere is insignificant as compared to absorption in higher layer of the atmosphere – the chromosphere – therefore granulation can be a source of stationary heating up of the chromosphere. For this absorbed energy of noise should be balanced by the energy radiated outside by the chromosphere. Studies of such conditions of heating up were made in the United States, and also in the USSR (E. Ye. Dubov, 1960).

In connection with this one should note the essential contribution of S. B. Pikel'ner who examined in 1960 the influences on convection of the magnetic fields which are observed virtually everywhere on the sun. A magnetic field according to his calculations represses turbulence faster than convection. Therefore if a magnetic field appears and grows, then, suppressing turbulence, it facilitates the passage of hot convection streams upwards, creates the very additional influx of energy to the upper layers and the increased glow, intensification of emmision in corresponding lines. These considerations help to understand the cause of formation of faculae and flocculi – regions of raised glow on the sun.

Studies of statistical properties of the undisturbed solar photosphere (field of speeds, magnetic field, field of brightness) with the application of correlation analysis have been begun at the Main Astronomical Observatory, AN SSSR, by G. Ya. Vasil'yeva and others in 1960, using the magnetograph of the Main Astronomical Observatory, AN SSSR, and equipment for photoelectrical registration of brightness. It was found that 1) the maximum of power spectra of the magnetic field and radial velocity was at $\sim$30,000 km, 2) the magnitude of the dissipation of the energy of turbulent motion is $5 \cdot 10^3$ ergs/gm·s, assuming local-isotropic turbulence.

Detailed spectral investigations of active regions on the sun started in 1954 at the Crimean Observatory led also to a conclusion concerning the presence in them of a fine emission structure, namely: emission in lines and continuous emission, as observations

at high resolving power showed, are concentrated in little, short-lived grains, on comparable in size with the resolving power of the telescope. Frequent characteristic emission in the lines was revealed in the form of brilliant wings of lines, called "mustaches," extended along the spectrum.[1] Further detailed spectrophotometric and kinematographic study of this phenomenon showed that here we are dealing with something similar to an explosion, ejection of streams or formation of shock-wave fronts moving upwards and downwards. These explosions appear on various depths, and in those places of the sun's atmosphere where activity is noticeably expressed in the form of the formation of solar spots, rapid growth, etc. A fine structure was revealed in the emission of flares and prominences: in good images its elements are similar to "mustaches" (by the mechanism of expansion) (A. B. Severnyy, 1954-1959). After several years a conclusion concerning the fine structure of flares was reached abroad on the basis of several other considerations of Z. Shvestk (Czechoslovakia), Z. Suyemoto (Japan), K. O Kippenkhoyer (FRG).

Detailed investigations of emission spectra of solar flares were started in 1948 at the Krymsk Observatory (E. R. Mustel', A. B. Severnyy and others). For the first time an explanation of the very great width of emission lines was found; for a number of flares it is connected with broadening by interatomic electrical fields (Stark effect), in other cases lines expand due to Doppler effect as a result of macroscopic motions of substance. To clarify the cause of distinction in the mechanisms of the broadening of spectral lines a collective of colleagues of the Crimean Observatory carried out a spectral investigation of a large-power discharge — linear pinch effect in hydrogen — which showed that across the discharge expansion is basically Stark, and along the axis it is connected with macroscopic motions. These and earlier investigations of the change of magnetic fields during flares, and also the study of positions of flares relative to magnetic fields led to a conclusion about the important

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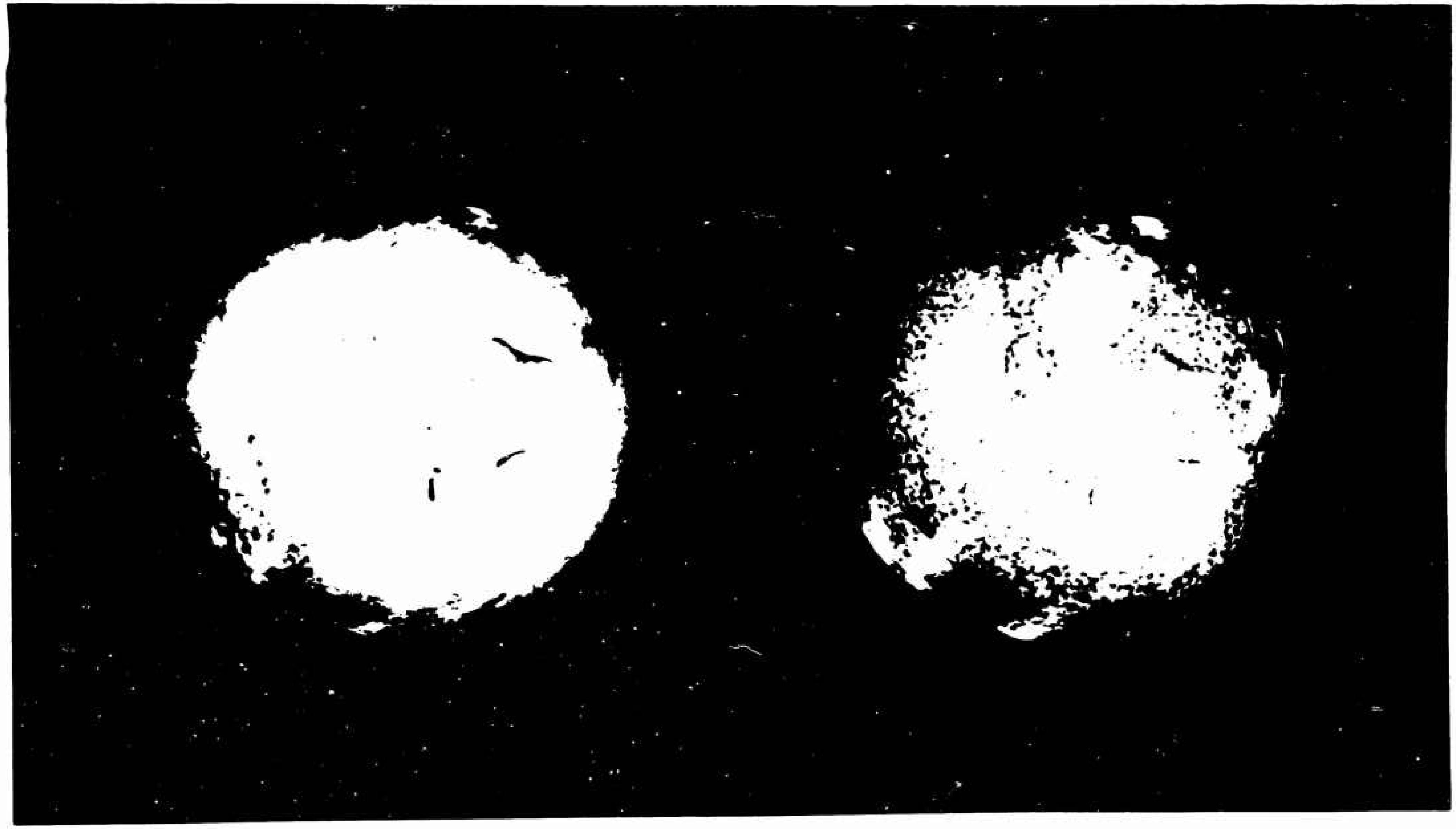
[1]"Mustaches," apparently are analogous to so-called bombs — a phenomenon observed in 1917 by F. Ellerman (United States) and then forgotten.



Simultaneous images of the sun in rays of the hydrogen H_{α}-line (on the left) and the K-line of vapors of ionized calcium (on the right). These photographs are obtained regularly following the program of the solar patrol on the double spectroheliograph of the Crimean Astrophysical Observatory.

Examples of the fine structure of emission in spectra of active regions. (narrow dark lines long spectrum, appearing near strong H_α, H calcium and other lines; negative images).

role of magnetic fields in the phenomenon of flares and about the possibility of a process analogous to the pinch effect, leading to fast compression and heating up of solar plasma. Crimean astrophysicists obtained data about temperature (near 10,000°) and electron density in flares, which then were repeatedly confirmed by others of our authors (for example, at the Astronomical Observatory of Kiev State University, Main Astronomical Observatory, AN SSSR and others) and abroad. Study of the physical state of hydrogen and the continuous spectrum of flares also led to a conclusion that the source of energy of flares has a nonthermal nature, i.e., cannot be obtained due to redistribution of thermal energy inside the atmosphere of the sun. We meet analogous phenomena in the case of powerful emission for certain nonstationary stars (A. B. Severnyy, 1957-1960). The nonthermal character of the energy of solar flares is also indicated by such phenomena as flares of X-radiation and emission in the radiofrequency band, generation of cosmic rays from flares, etc.

Study of the emission spectrum of helium in flares basically confirmed data obtained for the spectrum of hydrogen, but showed that the glow of this element appears in a somewhat hotter region of the

Explosion on the edge of the sun. Emission in H_α line strongly expands due to the fast motion of hydrogen in the direction of the earth (with a speed near 500 km/s).

solar atmosphere; it also showed that overpopulation of metastable levels of helium and other peculiarities of the state of atoms of helium testify to the considerable role of electron beams in the impact excitation of atoms of heium (N. V. Steshenko and V. L. Khokhlov, 1960-1962).

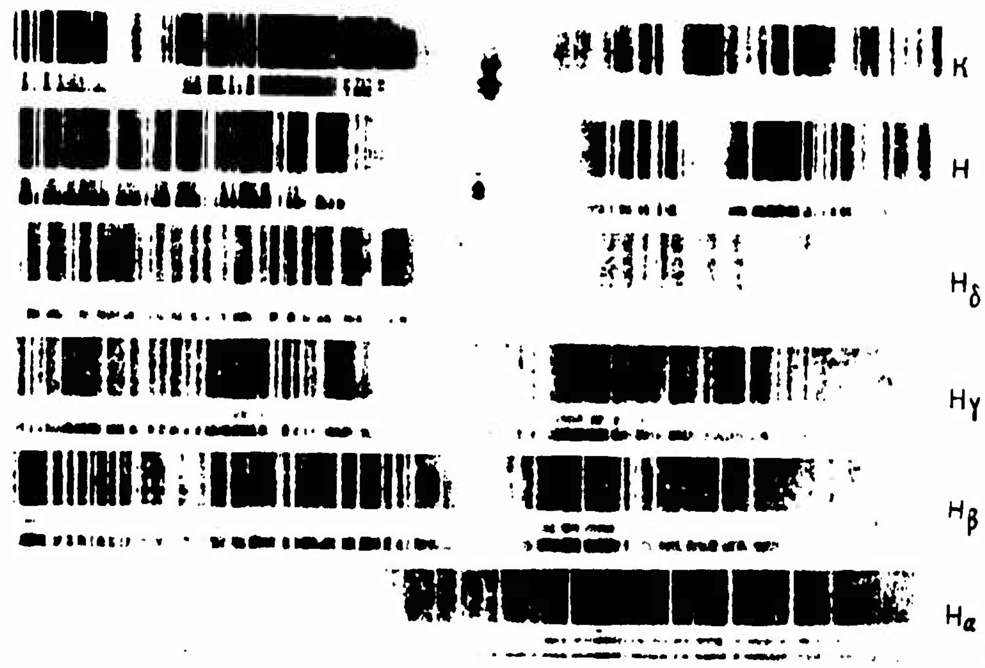
Further, during detailed study of the spectrum of flares above the edge of the sun's disk and its changes in time clearly expressed stratification was revealed (separation on layers) of the physical conditions of flares with respect to height in the atmosphere of the sun. A distinction of the time sequences of the glow of different elements again confirmed the idea of a flare as an explosion which occurs at a certain height in the solar atmosphere and from the region of which propagates a shock-wave front, causing successively a glow in various layers of the sun's atmosphere (N. N. Stepanyan, 1961-1963).

Such powerful phenomena as a flare cause general interest and attract the attention of astrophysicists. Partly because of this the spectral study of other, "weaker" manifestations of solar activity is allotted less attention; furthermore, study of spectra here is hampered in view of the small "contrast" of the phenomenon if we do not consider prominences above the edge of the disk. For these

reasons study of the spectra of faculae, flocculi and solar spots did not lead to new conclusions of fundamental value either here or abroad, although certain authors obtained separate important and very useful information concerning the physical state of active regions. Thus, T. V. Krat at Pulkovo in 1947 determined the temperature and pressure in spots and found that gas must be rarefied, which is natural to expect proceeding from the condition of constancy of full (gas plus magnetic) pressure on the edge of the spot-photosphere. However, if we rely on the theory of radiation equilibrium, in favor of which we have photoelectrical measurements of the Moscow astrophysicist G. F. Sitnik (1956), then in a spot one should expect an increase of pressure (V. S. Berdichevskaya, 1954). The temperature of solar spots and other physical conditions in spots were also determined by O. A. Mel'nikov and S. S. Zhuravlev (Astronomical Observatory of Leningrad State University, 1955-1956), Zemanek and others (Kiev, 1961), and A. I. Kornilov (1961).

T. V. Krat (1947) and O. N. Mitropol'skaya (1952-1955) from comparison of the spectra of faculae and photosphere found for faculae an intensification of lines of ionized elements and a weakening of the lines of neutral elements. The effect can be observed by an increase of temperature in the facula of several hundred degrees, which was first shown in 1931 by V. A. Ambartsumyan and N. A. Kozyrev. Furthermore, it turns out that not only temperature, but, apparently also density in the surface layers of faculae is higher than in lower layers (V. L. Khokhlov, 1956). The physical state of flocculi was examined by E. R. Mustel'. He showed that the glow of ions of calcium in H and K lines is excited by electron impact, and hydrogen in the H_α line by means of recombinations. With this can be connected the distinction of the form of calcium and hydrogen spectroheliograms, and also the unequal behavior of infrared lines of the calcium ion in an active region and over spots (E. R. Mustel', 1955; E. R. Mustel' and T. T. Tsap, 1956-1957).

Calcium chromospheric faculae were studied also by V. A. Krat from spectrograms obtained at Pulkovo from 1960 to 1963. The author found that chromospheric faculae observed in the H and K lines of



Emission spectrum of solar flare on disk. Black dashes on strong lines of hydrogen (H_α, H_β and others and calcium H and K). Light line along spectrum is formed by a sunspot (negative images).

calcium are located in the lower chromosphere (height from 0 to 1000 km) and constitute impregnations of hotter gas in the layer of gas limited in height and with kinetic temperature T_e not exceeding 5000°. For them an electron density of $n_e = 10^{13}$ and $T_e = 6000°$ are characteristic. Doppler "turbulent" speed in calcium faculae on the average amounts to 15 km/s.

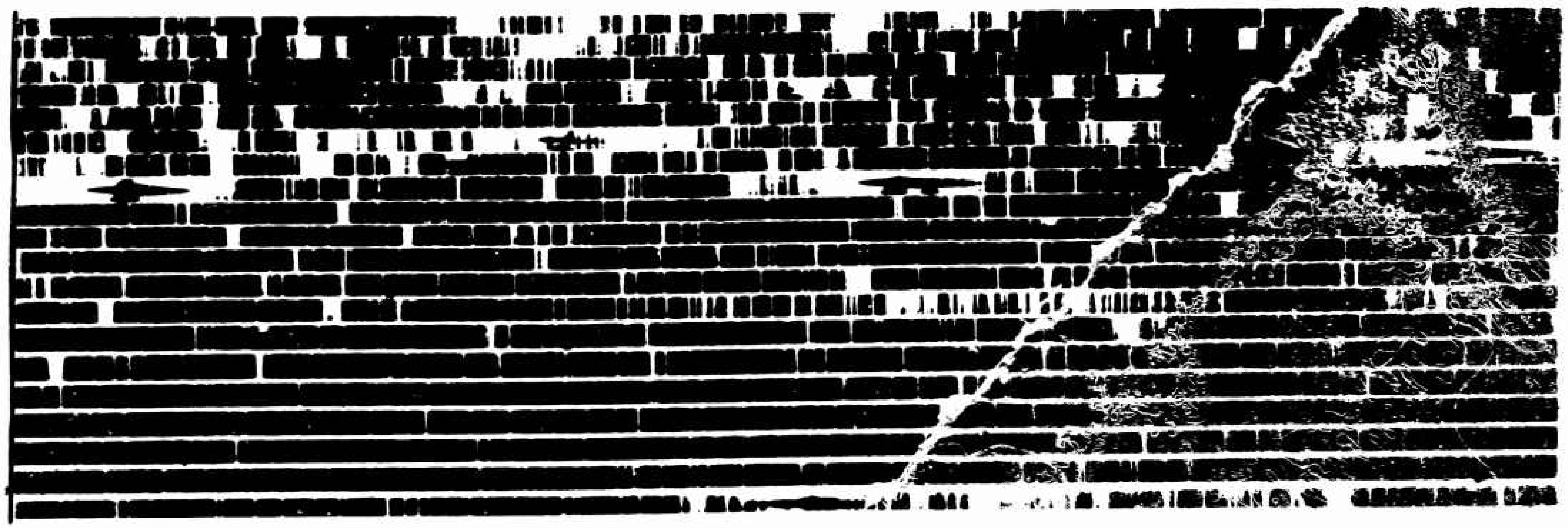
Spectroscopic measurements of motions in flocculi and surrounding chromsphere in 1953 led E. A. Gurtovenko and in 1956 L. M. Pravdyuk (Main Astronomical Observatory, AN USSR) to the conclusion that there is no motion of substance in flocculi, however, with large-resolution measurements of V. L. Khokhlova (1957) permitted concluding a rise of gas in the flocculi, the speed of which somewhat decreases with height in the atmosphere. Tangential motions in these formations were found also.

Spectral investigations of nonstationary processes were successfully augmented by cinematographic investigations of motions of the solar plasma in rays of the hydrogen H_α line. Thus, in 1954 in the Crimean Astrophysical Observatory, where for the first time in our

country this method was used, fast motions in solar flares were recorded, this considered to be always stationary formations. In the same place the fact of a growth of area simultaneously with the build up of a flare was determined (a phenomenon characteristic for explosions), the "supersonic" speeds (near 1000 km/s) a luminescent ejections from flares, pulsed extensions and reduction of brilliant conical protusions from flares with accelerations exceeding gravitational, and other phenomena were found (Ye F. Shaposhnikova, A. B. Severnyy, 1954, 1960). The presence of such rapid ejections was again (6 years later) detected in the United States by G. Atey and G. Morton. The connection of different flares with dark ejections and prominences was examined by Yu. M. Sloni (1957-1961) at the Tashkent Observatory. It showed in particular that the appearance of fast absorption ejections is characteristic for pulsed flares, for which the explosive phase is well-defined — fast rise to maximum brightness. In the Crimea it was found that flares are accompanied by frequent dark ejections and that each such ejection is connected with a flare; for a flare a rise of substance of the photosphere and intensififcation of ejections from the chromosphere is also characteristic (S.L Gopasyuk, M. B. Ogir', T. T. Tsap, 1963).

The motions of solar prominences reflect very unique behavior of solar plasma. An attempt to clarify the basic types of such motions made in the Crimea, led to a tentative division of all prominences into three classes: electromagnetic — with regular motion of substance along trajectories similar to lines of force of magnetic fields; quiescent, where motion is chaotic and eruptive, in which the ejection of an entire mass of a prominence almost radially from the sun is observed (A. B. Severnny, V. L. Khokhlova, 1953). Subsequently it was found that in quiescent prominences an isotropic turbulence can exist, causing actually observable fluctuations of density (E. Ye. Dubov, 1954-1955, 1957).

Besides work of the Pulkovo astrophysicists shown at the beginning of the chapter (p. 180), a large amount of research in the study of spectral of prominences was carried out in different observatories of our country (KrAO, Main Astronomical Observatory, AN USSR Observatory at the Kiev State University and others). All of them



Spectrum of emission of solar flare on the edge of the sun's disk. Wide dashes, appearing near certain strong lines. The spectrum was obtained 2? July 1959 using the echelle spectrograph at the KrAO. Here the whole spectrum of sun is in the form of a line scanning on a plate 13 × 18 cm (negative image).

Photography of a group of solar spots 18 August 1959.

lead to more or less identical results, analogous to those mentioned above: kinetic temperature of prominences - from 6000 to 10,000°, but electron density of these formations noticeably lower than for flares (near 10^{10} cm^{-3}). A conclusion was also made concerning fine filament structure of prominences (G. . . Ivanov-Kholodnyy, 1955). The peculiarity of excitation and helium glow in prominences was studied by I. S. Shklovskiy (GAISh, 1951), N. S. Nikitin (Astronomical Observatory of Leningrad State University, 1952), V. A. Krat and V. M. Sobolev (Main Astronomical Observatory, AN SSSR 1957-1960).

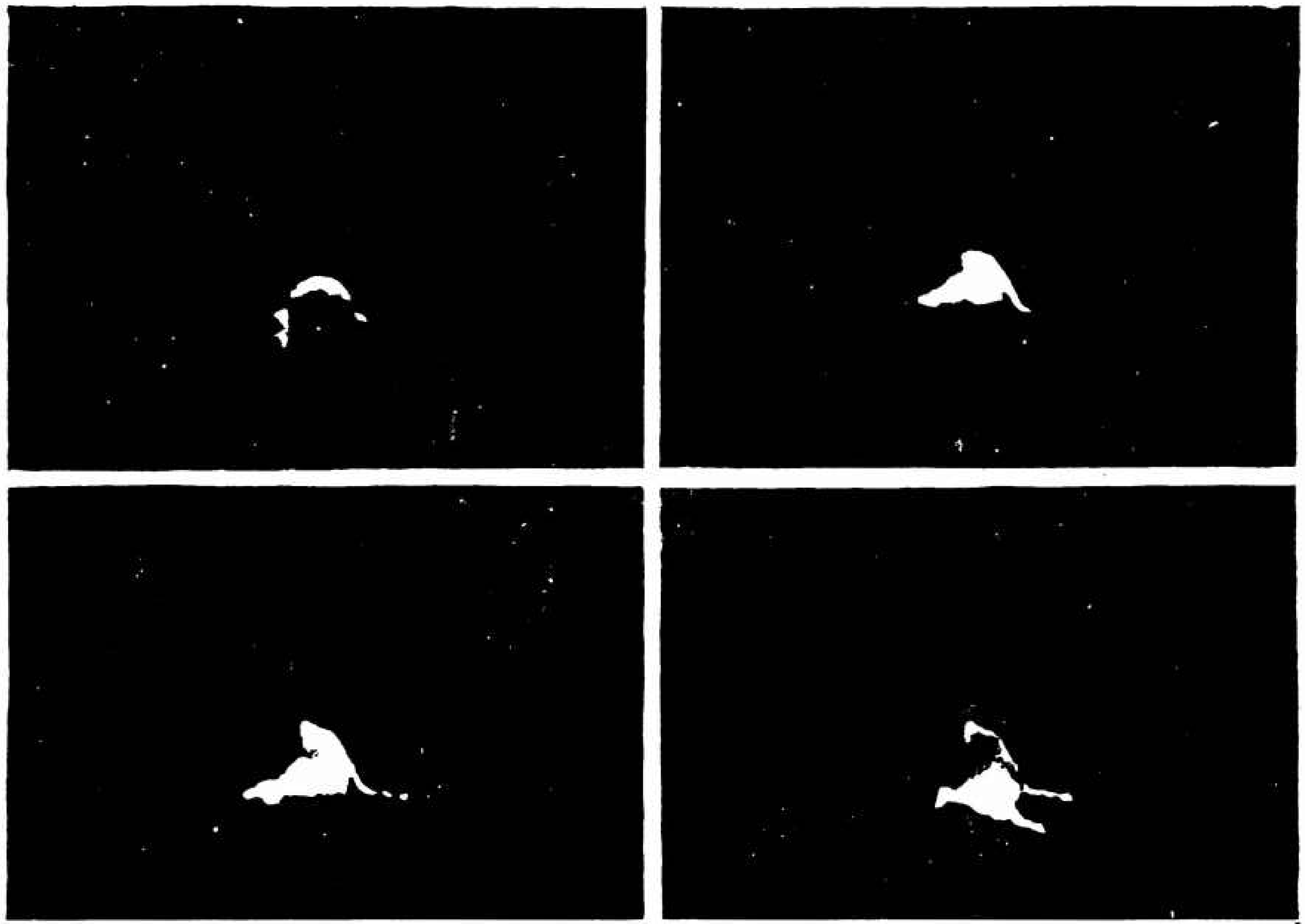
Studies of magnetic fields have a fundamental value for understanding processes occurring on the sun, especially for understanding the behavior of solar plasma. Systematic measurements of magnetic fields have been begun at Mount Wilson Observatory by J. Kheyl, who discovered in 1908 the Zeeman phenomena in the spectrum of solar spots. In our country measurements of the magnetic fields of solar spots were started by the photographic method in 1954 at the Crimean Astrophysical Observatory on the tower solar telescope (A. B. Severnyy, V. Ye. Stepanov).

Chromospheric faculae in the H_α line. Light clouds next to a dark spot, after photographs at the KrAO 23 August 1959.

Such a method, however, permits revealing only strong magnetic fields; to study weak fields in 1956 on the same telescope the photoelectrical method of measurement was used using a magnetograph. The successful realization of such method requires great length of the solar spectrum (Crimea – 30 m). At present magnetographs are also operated at the Pulkovo Observatory, IZMIRAN and SibIZMIRAN.

The result of cooperative work on measurement of the magnetic fields of solar spots for the International Geophysical Year was the creation of a detailed catalog of magnetic fields and polarities of spots (V. Ye. Stepanov, Ye. F. Shaposhnikova, N. N. Petrova, 1963).

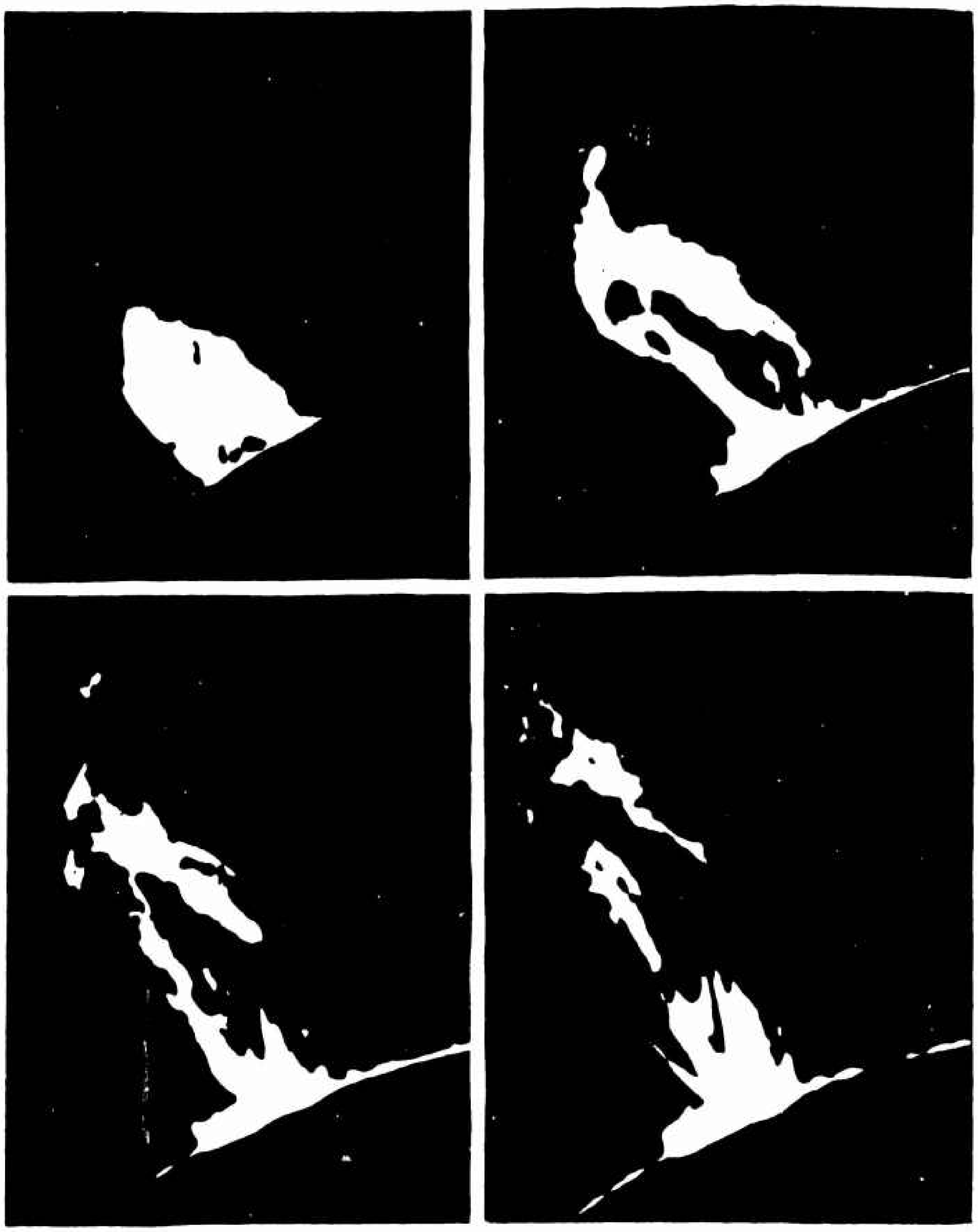
The method of photoelectrical recording of weak fields was first time successfully used by G. V. Babcock (United States, 1953) at Mount Wilson Observatory. But American researchers worked faster on



Consecutive photographs of a flare of 31 August 1956, made by filming with interference-polarization filter passing the H_α hydrogen line.

qualitative study of pictures of only the longitudinal magnetic field, obtained for the entire solar disk with low resolving power (over the surface of the sun). This brought them to strong averaging and coarsening of the picture of the field and partly to erroneous conclusions. A basic distinction of the method, used for example, at the Crimean Astrophysical Observatory, from the American method was the 50 times higher resolving power over the solar disk. Furthermore, the possibility of photoelectrical measurements also of the transverse field was first realized (V. Ye. Stepanov and A. B. Severnyy, 1959), which permitted (simultaneously with registration of longitudinal field) determining the position and value of the full vector of the magnetic field (an analogous method was developed in 1962 also at the IZMIRAN by E. I. Mogilevskiy, B. A. Ioshpa and V. N. Obridko).

Application of tools with high resolving power led to detection of the fine structure of magnetic fields (analogous to fine emission structure). For example, fields which with the low resolution used by the American astronomers were estimated usually as unipolar, turned out to be complex, multipolar fields, where maximum intensity and field gradients were increased not less than 10 times. As a result such peculiarities of the field and such changes were detected which had escaped observers until then. Thus, for example, to counterbalance the long-standing ideas founded on classical works of Kheyl about the magnetic field of spots as similar to the field of the top of a solenoid, it was clarified that there are serious deviations from this picture — impregnation of transverse fields, field eddy, concentration of field in separate braids and other heterogeneities which are revealed only with high resolution and by means of photoelectrical registration of transverse fields. The detection field heterogeneity over the surface of the sun forced the suspicion of field heterogeneities, in depth as well. And indeed the effect of very strong field vector rotation with depth was revealed in the region of solar spots (A. B. Severnyy, 1962). It is interesting that these peculiarities and other deviations from smooth movement of force lines (field eddy, neutral points) turned out to be characteristic for regions where different nonstationary processes appear ("mustaches," flares); for such regions also the appearance nearby of



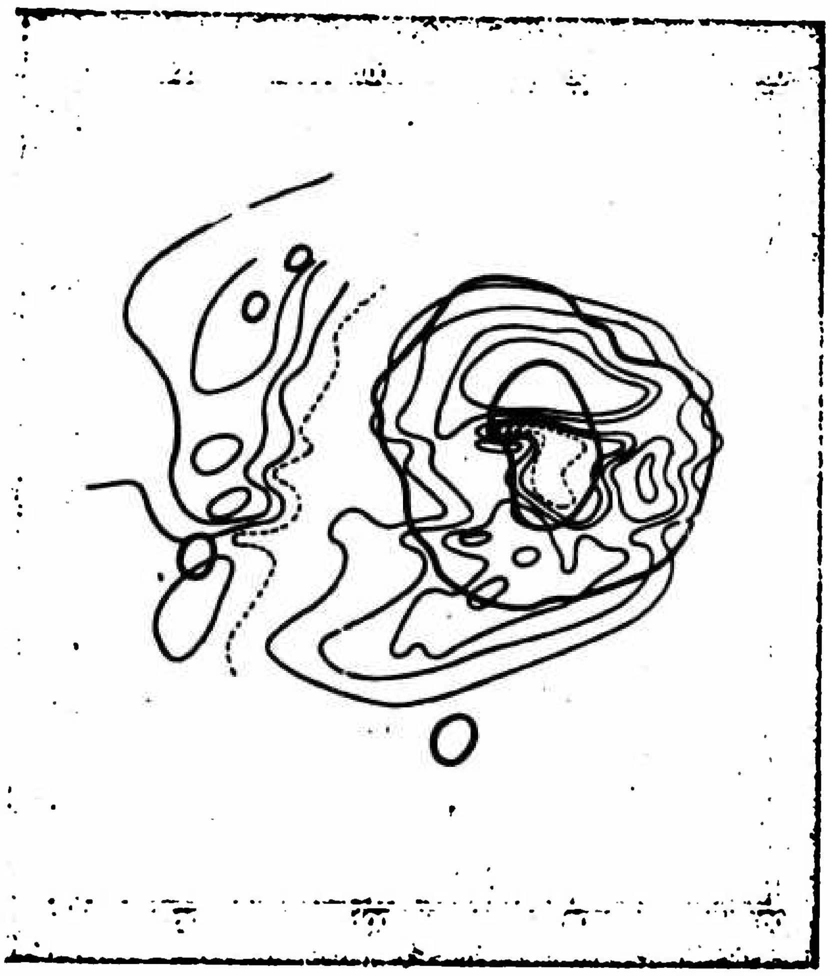
Consecutive photographs of a prominence of 19 May 1956, made by the method shown in the preceding figure.

Photography of the solar spectrum showing the splitting of a filament (on the left) in the magnetic field of a sunspot (light band along spectrum). The spectrum taken with a polaroid (on the left and in the center), and the same spectrum taken with a Mazatsuka, consisting of a plate of a quarter wave and polaroid lines oriented at 90° (on the right).

strong, oppositely directed electrical currents is characteristical, that once again favors the fundamental role of electromagnetic fields in the solar processes. These peculiarities of magnetic fields are unstable: measurements in 1957 – at the Crimean Observatory and subsequent measurements showed that, for example, "spasmodic" changes of magnetic field are connected with strong flares; before the flare fields are complicated and intensified, field gradients increase, "hills" of field relief and sometimes sunspots approach; after a strong flare the field is simplified, gradients drop, "hills" of the field and the time and spots themselves part, as though they are being "pushed apart" (A. B. Severnyy, S. I. Gopasyuk and others). Sometimes these changes have a temporary character -- the field is restored to practically the same as before the flare (this was indicated by a series of subsequent observations here and abroad).

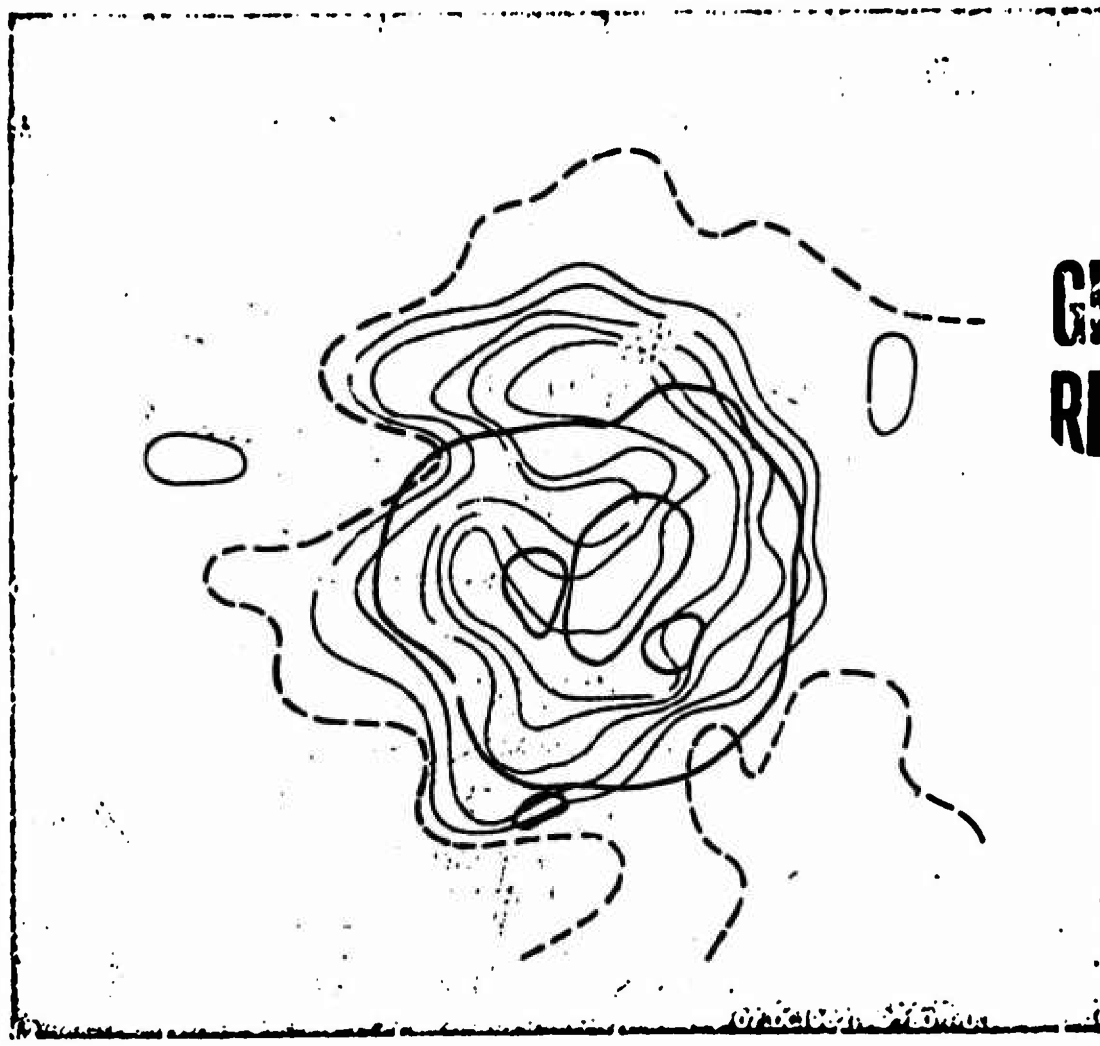
The appearance of spots and their development from magnetic "hills" with an intensity near 100 G according to G. Ya. Vasil'yeva (1963) also can be accompanied by strong nonstationary processes in the photosphere, a change of the magnetic field of the "hill" and a sharp change of radial velocity.

If we turn from the fine structure of the fields, then on the whole the field in sunspots turns out to be close to the field of a dipole, although on the external border of the spot fields of considerable intensity are directed almost horizontally to the surface of the sun (V. Bumba, 1960; A. B. Severnyy, 1965). In certain rare cases a vortex structure of a field is observed which can possibly be examined as a manifestation of so-called force-free fields[1] (V. Ye. Stepanov, S. I. Gopasyuk, 1964). However, these vortex fields repeat the vortex structure of the whole atmosphere around the spots (T. T. Tsap, 1963), which has a cyclonic origin as was shown in 1927 and 1941 by Kheyl and Richardson (United States).



Map of magnetic field, obtained with magnetograph and showing fine field structure. Thin lines - isogauss of longitudinal field in large spot 26 April 1958 (spots are outlined by heavy line); dotted line - neutral line.

[1]Force-free magnetic fields are realized in rarefied space plasma, when only the force supporting plasma equilibrium is a magnetic force ($\mathbf{j} \times \mathbf{H}$, $\mathbf{j}$ - current density, $\mathbf{H}$ - magnetic field strength), and the magnetic field takes a configuration corresponding to the condition of mechanical equilibrium, $\mathbf{j} \times \mathbf{H} = 0$.



Map of magnetic field, obtained with magnetograph and showing fine structure of field. Isogauss of longitudinal field, arrows - vector of transverse field in spot 7 September 1962.

Study of the magnetic field on the sun requires development of the theory of Zeeman phenomenon - splitting of filaments in a magnetic field for the case of absorption lines appearing in the optically dense atmosphere of the sun. This in turn will demand the solution of equations of radiation transfer in the presence of a magnetic field, i.e., taking into account polarization of radiation incident on a medium and dispersed (absorbed) by it. The solution to this problem was found by V. Ye. Stepanov (1958, 1960, and 1962) and then D. N. Rachkovskiy (1962). In particular, the latter obtained certain exact solutions to the problem of radiation transfer and showed the important value of the effects of magnetic rotation.

In the Crimea essential data were obtained on the connection of magnetic fields with structure and characteristic formations of

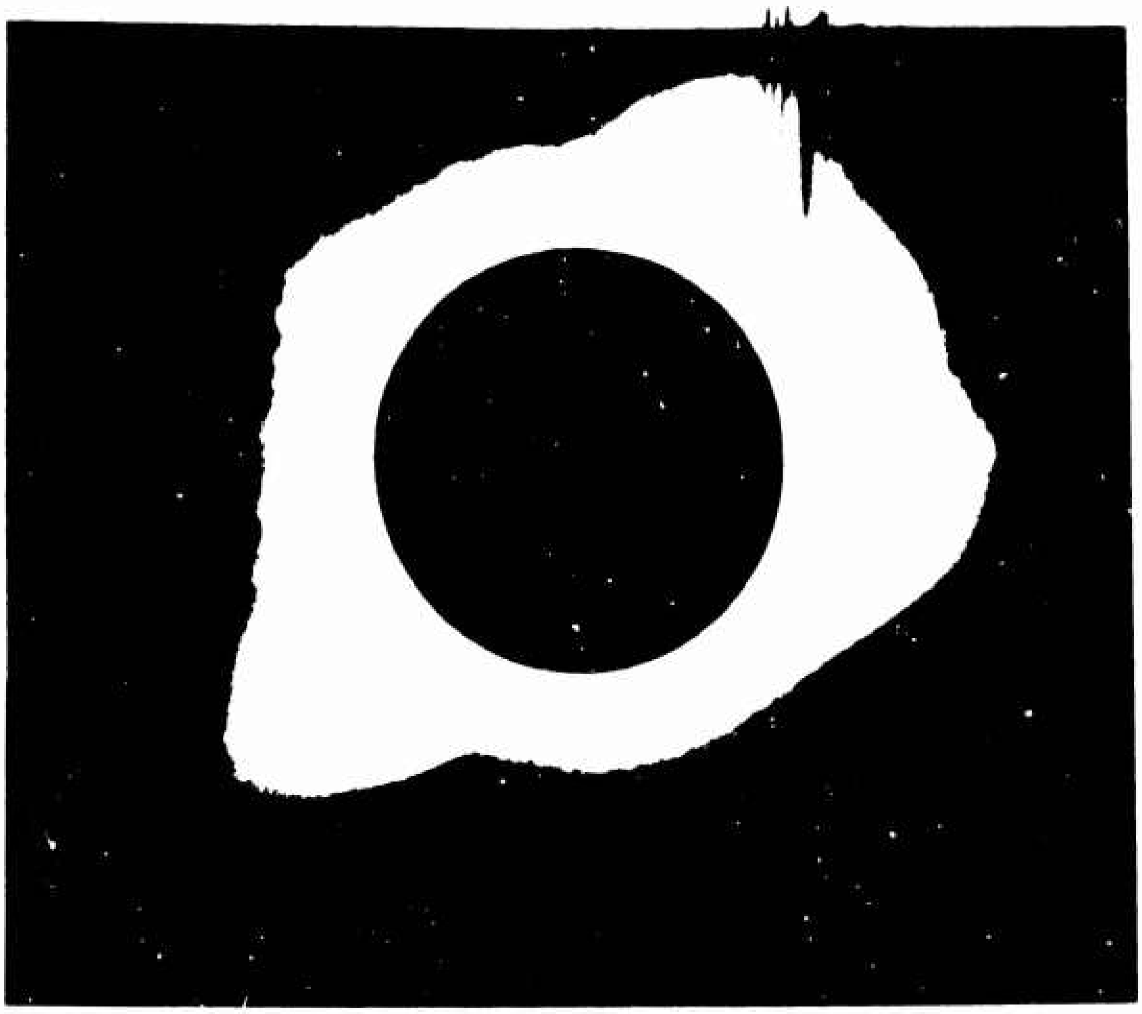
upper layers of the solar atmosphere. Thus, for example, V. Ye. Steph... n 1960-1961 confirmed results of American authors about the clc... ction between calcium flocculi and magnetic fields; moreover, he found a connection between brightness of these formations and field strength. He revealed a correspondence between longitudinal fields and the structure of the chromosphere outside spots: dark filaments and a chain of filaments of the chromosphere frequently are perpendicular to lines of equal intensity, i.e., as if they trace the lines of force. T. T. Tsap in 1963 showed that magnetic fields near spots repeat the vortex cyclonic structure of the chromosphere visible in rays of the H_{α} line. All of this testifies to the close connection of structure and state of the upper layers of the solar atmosphere with magnetic lines. In lower layers of the solar atmosphere the energy of gases and their motions essentially exceeds (outside spots) the energy of magnetic fields, therefore the fields passively follow matter. In upper layers (chromosphere and corona) the picture is opposite - motions of gases are controlled wholly by magnetic fields; here the magnetic field plays an active role, spreading to a rather high altitude. Moreover, in a number of cases fields are ejected together with solar plasma to considerable heights together with prominences (G. Zirin, 1961; B. Ioshpa, 1962). However, the question on interconnection of fields and motions of plasma in the solar atmosphere continues to remain one of insufficiently studied and difficult problems of solar physics.

Investigations of chemical and isotopic composition of the solar atmosphere have great cosmogonic value, especially if we consider those elements which burn during thermonuclear reactions inside the sun and stars. Although here there awaits still much to clarify, certain conclusions, indeed of preliminary character, have already been reached. F. Greenstein (United States) first noted the presence of perceptible quantities of lithium in the atmosphere of the sun, although in the presence of full mixing of substance inside the sun lithium should never be observed in its atmosphere. These conclusions with respect to lithium were confirmed in 1964 by E. Ye. Dubov and furthermore, indications were found of the presence of deuterium in atmosphere of the sun in amounts of $3-5 \cdot 10^{-5}$ of the hydrogen contents (A. B. Severnyy, 1957). The presence of such

elements as lithium, beryllium and deuterium, in the atmosperes of the sun and stars advances an important alternative: either in the stars there is no mixing, or thermonuclear synthesis reactions are not responsible for the formation of energy in the stars. There is still a third possibility, namely: these elements are formed in the atmosphere of the sun as a result of the capture of protons accelerated in solar flares by nuclei of nitrogen, carbon and oxygen. It is possible, however, to show that solar flares are not effective for such a process.

Much attention in the USSR was given to observations of solar eclipses, discovering so far the only possibility of exact quantitative study of the highest layers of the solar atmosphere — chromosphere and corona. Hardly the most important result here was study of the structure of the corona and its connection with the active formations in low layers of the solar atmosphere (spots, faculae, prominences). In 1954 Ye. Ya. Bugoslavska and S. K. Vsekhsvyatskiy studied motions and physical characteristics of parts of the corona. In particular, they found that bright streams appearing sometimes in the chromosphere (so-called spicules), lie at the base of coronal rays and have an identical slope, which possibly is connected with the action of a weak local magnetic field. This gave the authors cause to conclude the formation of coronal streams from the lower layers of the solar atmosphere. The same men found the dependence of the slope of coronal streams on the phase of solar activity and showed that coronal flows above faculae are inclined to the equator.

The connection of coronal streams (rays) with the magnetic field of the corona was repeatedly noted by many researchers, however, G. M. Nikol'skiy from photographs of the 1954 eclipse found that the directions of rays do not coincide with lines of force of the general magnetic field of the sun if one were to consider it as a dipole. A series of important conclusions, in particular about the speeds of electrons in the corona, about the change of emission intensity of the inner corona from eclipse to eclipse and on its dependence on position in the corona, was made by N. N. Pariyskiy (1939), G. A. Shayn (1947) and others. V. A. Krat studying the 1945 eclipse found



Appearance of solar corona 25 February 1952 (after photographs of the Tashkent Astronomical Observatory).

that the distribution of energy in the continuous spectrum of the corona is identical to the distribution of energy in the spectrum of the center of the solar disk. Many works were dedicated to study of the law of change of brightness of the corona with distance from the edge of the disk and integral brightness of the corona. In particular, V. B. Nikonov and Ye. K. Nikonova in 1947 found the dependence of integral brightness of the corona on the phase of solar activity. In 1948 V. G. Fesenkov established that the law of a drop of brightness of the outer corona at very large distances passes into the law of a drop of brightness of zodiacal light. Excellent photographs were obtained by A. A. Mikhaylov during the eclipse of 1936 for the purpose of studying the Einstein effect — deflection of rays of stars in the gravitational field of the sun.

Many different authors gave their attention to theoretical consideration of observations and theoretical development of questions

of the physics of the corona and chromosphere. Here first there should be mention of theoretical calculation of ultraviolet radiation of the corona and chromosphere, conducted in 1949 by I. S. Shklovskiy. He first noted the important role of X-radiation of these upper layers of the solar atmosphere in formation of the D-layer of the earth's ionosphere. He also carried out detailed theoretical research on the chemical composition and ionization of the chromosphere and corona on the basis of observations on total energy radiated by the corona in separate emission lines. Calculation led to the conclusion that in the internal (lower) corona the basic mechanism of strong ionization of atoms and excitation of coronal lines is the collision of atoms with fast electrons, which can appear under the action of induction electrical fields, connected with changes of magnetic fields of the sun. Further comparison of ionization and emission, calculated for various temperatures, with observations led to a conclusion concerning the presence of hot (temperature 1.2 – 1.4 million degrees) and "cold" (half a million degrees) regions of the corona. These and other questions, in particular the question about dissipation of the corona (examined in 1950 by S. B. Pikel'ner), its radio emission, etc., are examined in the monograph of I. S. Shklovskiy "Physics of the Solar Corona" (1962).

In 1957-1961 V. M. Sobolev solved the problem of the mechanisms of hydrogen and helium glow in the solar atmosphere. On the basis of theoretically obtained populations of quantum levels intensities of Balmer series lines and the Balmer decrement were calculated. It was shown that at $T = 7500°$ the main role in the excitation of the second level is played by the intrinsic emission of the chromosphere in the L_α line, and for the remaining levels by Balmer radiation of the photosphere and recombination.

B. M. Rubashev (1958) theoretically investigated problems of subphotosphere stratification and circulation on the sun, and also properties of motion of the zone of spotformation as manifestations of general circulation. Interesting conclusions about changes of the zone of spotformation in connection with the change of glow of the corona have been made recently by M. N. Gnevyshev (1961).

Very recently, in connection with the possibility of measuring X- and ultraviolet solar radiation using artificial earth satellites and rockets (see the section "Space Research"), a series of valuable experimental and theoretical studies have been made. Thus, in 1962 A. V. Yakovleva and V. P. Kachalov using geophysical rockets obtained very detailed solar spectra in the very near ultraviolet region (region of wavelengths exceeding 2000 Å) and identified the lines there. A. I. Yefremov and others (1961) using artificial satellites showed an intensification of X-radiation during solar flares and determined energy fluxes in different regions of the X-ray spectrum. S. L. Mandel'shtam and others in 1960-1964 measured radiation in the L_α ultraviolet line and obtained photography of the sun in X-rays. In 1961 V. K. Prolof'yev and A. V. Bruns (Crimea) by satellite vehicle measured energy in the ultraviolet line λ304 of helium. Extra-atmospheric data about ultraviolet radiation of the chromosphere and corona permitted a theoretical examination of physical conditions in the transition layer between corona and chromosphere (G. S. Ivanov-Kholodnyy, G. M. Nikol'skiy, 1961).

It is necessary, however, to note that extra-atmospheric investigations of ultraviolet and X-radiation of the sun have not yet been sufficiently developed, which is connected partly with difficulties in the realization of similar experiments.

In conclusion we will mention the influence of the sun on the earth. Most successfully developed here is the problem of solar corpuscular streams and their influences on the earth (E. R. Mustel' and others, 1963; S. K. Vsekhsvyatskiy, 1963). One of the main problems is that of localization the source of solar corpuscles on the sun, in particular those which cause the so-called 27-day magnetic perturbations on the earth. From many comparisons of these 27-day sequences with the passage of bright flocculi through the central meridian of the sun (1942-1958 E. R. Mustel' concluded that centers of activity (flocculi) generating corpuscles with speeds from 150 to 500 km/s and more are responsible for magnetic perturbations (subsequently localization was definitized — the source of perturbations was recognized as the solar corona above floccula). Analyzing a

peculiarity of centers of activity and different types of geomagnetic perturbations, E. R. Mustel' concluded the existance of two types of coronal streams: in those "quiescent" regions of the sun where there are no faculae there is a general outflow of gas condensations, leaving the sun with speeds of 300-400 km/s and carrying along "frozen" magnetic fields. Above active regions (faculae) the corona constitutes an accumulation of radially directed tubes of force lines (R-rays), spreading through the whole of interplanetary space. These tubes - particle fluxes - are souces of geomagnetic perturbations.

The idea of coronal rays as radially directed particle fluxes was developed also by S. K. Vsekhsvyatskiy and his colleagues, however the position of these fluxes was connected by them on the basis of observations of eclipses with chromospheric streams, in particular with filaments and prominences. From this point of view fluxes proceeding from the corona can take with them a magnetic field initially belonging to the active region. A series of considerations, and also measurements on interplanetary stations ("Mariner-2" and others) favors the idea that this field is force-free (E. I. Mogilevskiy, 1964).

An essentially different nature is characteristic of particles causing strong magnetic storms, auror polaris and Forbush effect in cosmic rays (storm with "sudden" beginning). They are generated by solar flares and spread with speeds from 500 to several thousand kilometers per second. Their generation (as also acceleration) is intimately connected with a flare of radio emission from the sun accompanied by solar flares, and with the passage of particle fluxes through coronal condensations (I. G. Moiseyev, 1960). A considerable part of strong flares generates also high-energy protons (10-100 MeV). which, approaching the earth "precipitate" in the regions of the polar caps, creating here so-called polar blockouts. A close connection of such blockouts with flares on the sun was shown by A. S. Dvoryashin (1961, 1963).

INTRINSIC VARIABLES[1]

Variable stars present an extensive class of nonstationary objects, the study of which is very important for the solution of various problems of stellar astronomy and the physics of stars. By variables we understand usually stars whose brightness is subject to fluctuations. In spite of the fact that essential changes of the spectrum of a star which may allow it to be considered nonstationary certainly must also act in some degree on the brightness of a star, it is included among variables, only if direct observations show a fluctuation of brightness at least in the narrow range of wavelengths. During thorough photometric investigations this usually turns out to be the case.

Variable stars can be divided into three large classes: eclipsing variables, pulsating and eruptive (explosive). Starts of the first class in general do not change in luminosity; they are binary systems with such orientation of the orbital plane for which at every turn of the terrestrial observer there occurs an eclipse of one member by the other (they are described in the section "Eclipsing Variables").

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[1]During the writing of this section by the friendly permission of B. V. Kikarkin his articles in the collection "Thirty Years of Astronomy in the USSR" and "Forty Years of Astronomy in the USSR" were used. The author is grateful also to V. P. Tsesevich for a number of valuable remarks.

Of pulsating variables more than 10,000 are known; their brightness changes, as the name shows, due to a pulsation of the upper layers of the star. Here are included stars of various masses and spectral classes with periods of pulsation from fractions of a day (star of type RR Lyrae) to tens (stars of type δ Cephei and RV Tauri) and hundreds of days (variables of type Mira Ceti). Here belong slow irregular and semiregular variables of the late spectral classes. For certain types of stars of this class exists a dependence between period and luminosity of the star, which makes (first of all the cepheids) the best indicator of distances in the universe. These stars are also joined by a period-spectrum dependence: the greater the period, the later the spectrum. The phenomenon of pulsating stars is ever more frequently examined as a stage of development of at least certain stars, normal (or almost normal) on other stages.

For an understanding of the evolution of stars still greater in value is the study of eruptive variables, which amount to around 1000. The number of newly discovered stars of this type grows rapidly. Here we include first young stars, apparently only finishing their gravitational compression, for which irregular (sometimes very fast) changes of brightness are characteristic. Spectra of these stars indicate stormy processes on their surface. Secondly, eruptive variables also include stars (nova and nova-like) whose brightness undergoes almost no change in the usual state, but from time to time suddenly increases hundreds and thousands of times. In recent years it has been proven that many of these stars are components of binary systems, sometimes very close. This circumstance perhaps is a necessary condition of their flares.

Noticeable changes in the brightness of variable stars make them easy to observe, making them "marked stars." Such important characteristics as type of changeability and period are easy to obtain from observations with the simplest devices. Variable stars are one of the most gratifying objects for study, since they are comparatively easily studied and nonetheless it leads to results

important for understanding the physics of stars and their evolution. The connection of certain morphologic characteristics of a series of variable stars (pulsating, nova) with luminosity makes necessary their study also for establishing integalactic distances and studying the structure of the Galaxy. This explaines the unchanging interest toward this region of astronomy — a frontier (by subject and method of investigation) between astrophysics and stellar astronomy.

A description of the history of the study of variable stars in our country in the prewar period is given in articles of B. V. Kukarkin in collections "Thirty Years of Astronomy in the USSR" and "Forty Years of Astronomy in the USSR," and here I will be limited to only a fleeting survey of these years.

Tsarist Russia left us a poor inheritance. Although even in the 1860's O. V. Struve was interested in the changeability of stars in the Orion Nebula, systematic studies of variable stars were begun and conducted at the end of the XIXth Century only at the Moscow Observatory. A small series of observations in the 1870's had been conducted by S. P. Glazenan. In the middle 1890's V. K. Tseraskiy and S. N. Blazhko organized the first systematic photographing of sky in our country, mainly in regions of the Milky Way. L. P. Tseraskaya discovered from these plates more than 200 new variables. At that time the discovery of new variables occupied a considerable number of astronomers, mainly at the Harvard Observatory. Systematic observations of new variables also occupied the "father of Soviet transitionists" S. N. Blashko (1870-1956), who, in particular, observed the effect named after him of periodic change of the form of light curve for certain stars of type RR Lyrae. At other observatories variable stars occupied only individual astronomers. A. A. Belopol'skiy at Pulkovo was one of the first to begin (also in the 1890's) spectral observations of variables. He is credited with the discovery of changes of radial velocities for the cepheids. At the same time observations of variable stars occupied V. V. Statonov at Tashkent, S. I. Belyavskiy at Pulkovo and then at Simeiz and several other astronomers.

Sergey Kikolayevich
Blazhko

1870-1956

After the revolution, opening to all an access to science, the numberous young people appearing at astronomical centers of the country had to decide upon their area of study. Only the Pulkovo Observatory and its devision at Simeiz had more or less contemporary equipment; of the university observatories only the Moscow Observatory and the V. P. Engelhardt Observatory at Kazan approached European observatories in technical equipment. The position was aggravated by the fact that certain conservative representatives of the senior generation prevented the work of young enthusiasts at the astronomical establishments, and the latter for many years remained in the position of amateurs. They were forced to find region of astronomy, where interesting results could be obtained with modest devices. Just such a region was the study of variable stars. Amateur astronomical societies in Moscow, Leningrad, Gor'kiy, Odessa and other cities played a large role in the organization of observations of variable stars; from among members of these societies

emerged many now widely known astronomers. P. P. Parenago and B. A. Vorontsov-Vel'yaminov in Moscow, V. P. Tsesevich in Leningrad, B. V. Kukarkin in Gor'kiy, D. Ya. Martynov in Kazan, N. F. Florya in Odessa and others organized and conducted systematic observations of hundreds of variables. Toward the end of the 1920's these investigations received such an impact that the question appeared of creating a special news organ, which became the bulletin "Variable Stars," founded in 1928 by the Nishniy-Novgorod circle of amateur physicists and astronomers.

To the same time belong the first attempts of systematization and comprehension of accumulated material and unification of Soviet researchers in variable stars. In 1930 took place the first conference of researchers in variable stars, beginning a series of subsequent conferences. In 1936 the Central Commission for the Study of Variable Stars was organized — now the Commission for Variable Stars of the Astronomical Council, AN SSSR, which until his death was headed by S. N. Blazhko,[1] and from 1956 by B. V. Kukarkin.

In the 1930's the main efforts of Soviet "transitionists" were directed towards the study of still uninvestigated variables, and also the cepheids and eclipsing variables. A mass transition was accomplished to photographic methods of study. New large observatories were built at Simeiz, in the national republics of the Transcaucasus and Central Asia. At Moscow, Simeiz, Pulkovo, Tashkent and Dushanbe chosen regions of the sky were systematically photographed. At the same time at the Abastumani Observatory V. B. Nikonov together with Ye. K. Kharadze and P. G. Kulikovskiy

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[1]Blazhko, Sergey Nikolayevich (1870-1956). From 1893 to the end of his life was an astronomer at the Moscow Observatory; from 1918-1941 its director. An honored worker in science of the RSFSR. Basic areas of activity: astrophysics, stellar astronomy, practical astronomy. In 1895 one of the first to begin photographic study of objects in outer space — stars, planets, meteors; special attention to the investigation of variable stars. The author of three university courses on the main divisions of astronomy (1940, 1947, 1948).

make the first photoelectrical observations of variables in the USSR. Our country entered the forward lines of world science. Large general works appeared. A detailed survey of information on variable stars was given in the collective monograph "Variable Stars," written by B. V. Kukarkin and P. P. Parenago (intrinsic variables), D. Ya. Martynov and V. P. Tsesevich (eclipsing variables). N. F. Florey, M. S. Zverev and others (methodology). B. A. Vorontsov-Vel'yaminov write a fundamental work on novae. At the P. K. Shternberg Astronomical Institute under the leadership of P. P. Parenago and B. V. Kukarkin began the composition of a card bibliographic catalog of variable stars, which was roughly completed by the summer of 1941.

War delayed the development of Soviet astronomy. The two largest observatories — Pulkova and Simeiz — were destroyed. Normal operation of the majority of the others was impossible. Among those perishing on the astronomer front was the talented researchers in variable stars N. F. Florya. However, in spite of difficulties and irreplaceable losses, not only was much of value accumulated, but also certain observations of variable stars continued.

After the victory over fascist Germany, along with adjusting of normal work, before Soviet researchers of variable stars arose a new problem. Before the war the designation of newly discovered variables and the publication of information on variable stars were conducted in Germany by R. Prager, and later by H. Shneller. Now Soviet astronomers, in the first place thanks to the card catalog of variable stars created at the GAISH, could take on this labor-consuming and complex work, no longer possible in Germany and rejected even by the Harvard Observatory — the largest center for the study of variable stars at that time. In March 1946, the Executive Committee of the International Astronomical Union (IAU) received a proposal from the Academy of Sciences of the USSR and assigned to Moscow astronomers the composition of catalogs of variable stars and the designation of newly discovered variables. Since then this work has been conducted continuously by the joint

Aristarkh Apollonovich
Belopol'skiy

1850-1934

efforts of the Astronomical Council of the Academy of Sciences USSR and the P. K. Shternberg State Astronomical Institute.

In the first postwar years great successes were attained in the reactivation and development of observations. Photoelectrical photometry except for Abastumani was conducted now at Kazan and at the new Crimean Astrophysical Observatory. Systematic photographing of the entire sky was continued (Dushanbe and then Odessa), and also chosen regions of the sky (Moscow, Tashkent, Tartu, L'vov, Kazan and others). In these years the Soviet students of variable stars carried out a number of works, which became the largest contribution to the study of the structure of the Galaxy and the evolution of stars. Here we must first mention the work of B. V. Kukarkin and P. P. Parenago on space distribution and kinematic characteristics of stars of various types.

Let us now turn to a survey of the most important achievements of Soviet astronomers in the study of separate types of variable stars. Basic attention will be allotted to works carried cut in the last decade, and also fundamental investigations and works interesting from the point of view of contemporary problems. Interests of the reader-layman forced the author not to mention many works valuable for their own time.

The cepheids present special interest because of the clear relationship between period and luminosity. The investigation of these stars always was the center of attention of Soviet astronomers. Even toward the end of the 1930's observations were conducted of all cepheids accessible then, and their periods and form of light curves were definitized. The first important results were obtained in the study of changes in periods of the cepheids, of great interest in view of their possibly evolutionary character. B. V. Kukarkin and N. F. Florya in 1932 found that instability in the period of a cepheid increases with the length of the period. P. P. Parengo (1956) conducted the as yet most complete study of changes in periods of the cepheids. He refuted the stabilized opinion about continuous change of periods of the cepheids and showed that the new value suddenly, by a jump changes the old; decreases of period are encountered just as frequently as increases. Now the study of variability of periods of the cepheids obtains specific value in connection with the study of evolution of stars of this type.

In the 1930's B. V. Kukarkin and P. P. Parenago made numerous investigations of basic dependences for the cepheids — connection of form of light curve with period, amplitude with period, frequency allocation of amplitudes. The period-luminosity dependence was the subject of many numerical investigations, started in our country nearing the end of the 1930's: especially much work in this direction was done by Kukarkin. In 1949 he set the result of his own investigations of the period-luminosity dependence, offering the best formula at that time for this dependence. Its zero-point, i.e., calibration in absolute values (by inspected data about proper motions of the cepheids) turned out to be $0^{m}.5$ brighter than in the

classical dependence of H. Shapley, obtained in 1930 at the Harvard Observatory. Such a correction to Shepley's zero-point was obtained in 1944 by O. A. Mel'nikov at Pulkovo. He also carried out important spectral studies of the cepheids, in particular proved the presence of turbulence in the atmospheres of δ Cep and η Agl.

The question about the zero-point of the p-l relation received a new advance in 1952 when the first results of a study of the galaxy M 31 with a 200-inch reflector impelled V. Baade (Mount Palomar, United States) to express his assumption that this zero-point should be brighter by $1^{m}.5$ than Shapley had previously figured, so all distances in the universe determined by the cepheids must consequently be doubled. Among the many works carried out in this connection by Soviet astronomers (Yu. P. Pskovskiy, A. Ya. Filin, P. N. Kholopov and others), we should note the investigation of P. P. Parenago, who in 1954 based on processed data of Blaauw and Morgan about proper motions of 18 cepheids (determined in the very best manner) and on other considerations obtained a correction to Shapley's zero-point equal to $-1^{m}.0$. This conclusion was confirmed by I. L. Genkin in 1963.

The most important event in study of cepheids was the detection – independently by P. N. Kholopov and J. Irvin – of cepheids in open clusters. One of such cepheids (U Sgr. in M 25) was known even by P. Deutsch in 1925, but the conviction was prevailing that variables, in particular cepheids, are not encountered in open clusters. P. N. Kholopov (1956), refuting this conviction, gave the first list of cepheids (and other variables) in these clusters. He first studied the question about the reality of a physical connection of cepheids with clusters and showed its possibility. The range of open clusters (and consequently, of cepheids – their members) from the beginning of the 1950's began to be determined with very great accuracy. Therefore from 1955 in the United States numerous works for the purpose of detection and investigation of cepheids in open clusters turned up, leading to the appearance in 1961 of Kraft's currently most widely used p-l relation, based on the luminosity of five cepheids in clusters. Its zero-point is $1^{m}.4$ brighter than Shapley's.

B. V. Kukarkin even in 1954 assumed that the dispersion of the p-l relation is real and is connected with different morphologic peculiarities of cepheids. The work of American and Soviet astronomers 1958-1966 confirmed this, luminosity of the cepheids turned out to be connected with their color and form of light curve.

From ideas on the evolution of massive stars and position of the cepheids developed by A. Sandage and M. Schwarzschild in 1952 on color-luminosity diagrams of open clusters, it followed that cepheids are a late stage of development of massive stars. The striking similarity of space and kinematic characteristics of these objects shown, in particular, in works of Parenago, had a natural explanation. Ye. N. Yefremov, laying the foundation in 1964 for several cepheids belonging to coronas of clusters, revealed the existance of a clear correlation between periods of cepheids and ages of the clusters to which they belong, predicted a hypothesis about the origin of cepheids from B-stars. Settling on this hypothesis, I. M. Kopylov (1964) concluded that masses of cepheids are included in the limits of 3-12 masses of the sun.

Using the results of his own preceding works, N. Yu. Yefremov and I. M. Kopylov (1966) inspected data about the cepheids being in stellar groupings; they concluded that a star can be cepheid through several tens of millions of years. The same appraisal in 1965 was given by a group of German theoreticians (R. Kippenhahn and others) for time between the first and the last "approach" of a star with mass of 5 solar masses into the spectrum-luminosity band occupied by cepheids. But the total time of a star stays in this band, following from theoretical calculations, is much less and coincides with the time following from the relative quantity of B-stars and cepheids (10^6 years), so that there is no need in initiating a series of difficulties on the assumption that only part of the B-stars turns into cepheids. Peculiarities of evolutionary tracks of massive stars could be explained by a decrease of the number of cepheids of small periods. A similar conclusion was made in 1966 by I. Iben and R. Kraft.

According to data of Yu. N. Yefremov and I. M. Kopylov, cepheids on the average are $0^m.5$ weaker than the Kraft p-l relation indicates. This result is entirely explained by the fact that in their work the moduli of ranges of clusters were determined using calibration of the initial main sequence, proposed by I. M. Kopylov in 1963. Acceptance of the initial main sequence of Kopylov thus removes the contradiction between luminosity of cepheids, determined by proper motions and considering them as belonging to clusters.

Of other recent studies of cepheids in our country, we should note the B, V photometry (plates of the 70-cm reflector of the GAISH) of both parts of the double cepheid CE Cassiopeiae in the cluster NGC 7790, made for this system first and increasing from 5 to 7 the number of cepheids in the nuclei of the clusters, studied by contemporary photometry methods (Yu. N. Yefremov, P. N. Khalopov, 1965). Thus the problem set by V. Baade for the 200-inch reflector was solved. I. N. Latyshev (1964) and N. Ye. Kurochkin (1965) offered methods for determining luminosity of cepheids by their light curves and radial velocities. G. S. Tsarevskiy, V. Ureke (Rumania) and Yu. N. Yefremov (1966), compared positions of all known open clusters and cepheids, confirmed the presence of cepheids in coronas of clusters. Tsarevskiy conducted also narrow-band observations of a series of cepheids.

Variables of type RR Lyrae (subsequently for brevity called Lyrids). In the study of these variables one should first note the merits of V. P. Tsesevich, who already in the 1930's organized jointly with B. V. Okunev a service for the observation of the Lyrids. This service ceased in 1936 and was renewed in 1958 by decision of the Xth Congress of the IAU; the gap in observations is filled at present by the efforts of many observatories, especially the Odessa and Rostov observatories. The voluminous material collected by V. P. Tsesevich for 40 years permitted him to make interesting conclusions concerning the character of changes of periods of the Lyrids, which turned out to be connected with their space-kinematic characteristics: Lyrids possess a spherical component of more

unstable periods. Investigations of the Blazhko effect for these stars – a phenomenon whose nature has not been clarified finally until now belong to V. P. Tsesevich.

An important work on determination of the absolute stellar magnitude of Lyrids by the proper motions was carried out in 1953 by Ye. D. Pavlovskaya. The mean value he obtained ($M_{pg} = +0^{m}.5$) soon was confirmed by P. P. Parenago, originating from dynamic considerations, and in recent years by American astronomers according to the few globular clusters whose range can be determined without the Lyrids, with respect to the position of the main sequence. Ye. D. Pavlovskaya in 1960 revealed also a fictitious quality of a considerable portion of the periods found by S. I. Gaposhkin for Lyridae of the galactic center, proving thereby the absence of the anomalous nature attributed to them.

For an understanding of the origin of Lyrids of the galactic corona the cycle of works of N. Ye. Kukochkin is of great value, carried out in the last decade on detection and investigation of Lyridae in a wide circle of globular clusters. P. N. Kholopov in the 1950's studied the distribution of Lyrids in the internal regions of these clusters, showing that, as for all stars of a globular cluster, they will form three zones with sharply different density. Lyrids in globular clusters were also the subject of a series of investigations of B. V. Kukarkin, who jointly with N. P. Kukarkin first showed a Blazhko effect for certain of them.

Criteria of Lyrids belonging to different components of the Galaxy were investigated by many authors. Recently even more indications have been accumulated that Lyrids with periods smaller than $0^{d}.2$ belong to the flat component and have a luminosity considerably smaller than for normal Lyrids. This conclusion was confirmed by M. S. Frolov in 1963, who, using a modified Vesselink method, obtained also a period-luminosity dependence for the Lyrids.

Pulsating variables include the late giants and supergiants.

Investigation of these stars has occupied many Soviet astronomers. V. V. Sobolev in 1947 assumed that long-period variables consist of a hot nucleus surrounded by a shell of great optical thickness, which also explains the presence there of bright lines and a low-temperature absorption spectrum. This conclusion in general was of great value for understanding the nature of giants. Still earlier G. A. Shayn in 1935 explained the anomalous Balmer decrement in spectra of these stars by unequal shielding of radiation in Balmer lines by molecules titanium oxide. The influence of the molecular bands also explains why the visible amplitude of fluctuations in brightness for these stars exceeds bolometric. Space-kinematic characteristics of these stars are the subject of long-term investigations of V. V. Ikaunieks; their light curves are investigated by Yu. I. Yefremov. V. P. Tsesevich established that semiregular variables of the type RV Tauri possess extended atmospheres; Ye. D. Pavlovskaya concluded that these stars belong to an intermediate component or enter in the composition as both flat and spherical components of the Galaxy.

Place of pulsating variables in stellar evolution. A very significant contribution was introduced by Soviet astronomers in the theory of pulsation of variable stars. First we must note the cycle of works of S. A. Zhevakin, carried out in the 1950's. He developed a theory that natural oscillations of variable stars are maintained thanks to the existence of a peripheral zone of twice-ionized helium, absorbing during compression the excess radiation arriving from within, and intensively radiating it outside during expansion. The theory of S. A. Zhevakin explained the phase shift between light curves and radial velocities, which earlier could not be explained by the pulsation theory. This theory gradually obtained even more supporters and now is being developed both in our country and abroad. She explains, apparently, a series of regularities for cepheids but in the opinion of certain astronomers, it cannot be extended to all types of pulsating variables.

The place of pulsating variables in stellar evolution was

actively studied in recent years, especially after the appearance of the works of B. V. Kukarkin (1943-1949) on the space distribution of variable stars. These works led to the appearance of the conception of the existence of flat, intermediate and spherical components of the Galaxy, formed by subsystems of stars of various physical types. This conception turned out to be intimately connected with Baade's conception of two types of stellar propulation (1944), founded on differences in the form of the color pattern — the magnitudes for populations of two types; developed in the works of P. P. Parenago, it has played a large role in stellar astronomy. B. V. Kukarkin revealed that a series of types of variable stars contains stars which are in various components of the Galaxy and have, consequently, various ages. There are such cepheids whose seventh part is similar to cepheids of globular clusters and are in the spherical component, whereas others are young stars and will form a very flat subsystem; myrids, of which the most long-periodic belong to the intermediate component (population of disk, in contemporary terminology), and the short-periodic are in globular clusters; Lyrids, which we have already mentioned, are probably stars of the type RV Tauri.

What explains the proximity of morphological characteristics for a series of pulsating stars of various age? At present the question stands thus: either pulsating variables are anomalous stars and because of this anomalous quality on various stages of their life they manifest themselves as variables of different types (such a possibility was spoken of by P. N. Kholopov (1965), who assumes that classical cepheids are the ancestors of cepheids of the spherical component, and star of type α^2 CVn can perhaps evolve into stars of type RR Lyrae. Certainly, we are speaking here about a change of morphologic and not space-kinematic characteristics of stars), or there simply exist such regions on the color-luminosity pattern (stars falling in them signifies the approach of a defined stage of evolution) in which stars become unstable and start to pulsate, being fully normal on other stages. Stars of differing age with different internal structure and mass, upon falling into the same region pulsate similarly, but naturally,

not quite equally (classical cepheids and cepheids of spherical component). A second point of view divides the majority of astronomers; it agrees well with the Schwartzschild-Sandage-Hoyle pattern of stellar evolution.

Thus, I. M. Kopylov in 1959-1960 noted that a series of variables and peculiar stars (type β Cephei, magnetic stars, Am stars and others) is positioned on the color-luminosity pattern near the upper edge of the main sequence, just where after hydrogen in the central parts of the stars burns out the compression of their nuclei begins. The changeability of such stars according to I. M. Kopylov can appear as a result of structure reconstruction, leading in particular to a change of the law of axial rotation. Such an explanation of the changeability of stars of type β Cephei was developed in the works of V. V. Porfir'yev, G. T. Oliynik (1963-1964). A second band of instability stretches from supergiants of class K to the dwarfs of class A; in it are found the Lyrids, cepheids, and stars of the type RV Tauri. Its existence is caused apparently by the fact that corresponding combinations of luminosity and surface temperatures signify the approach in a star of such conditions (for example, defined depth of bedding of the zone of ionized helium, according to S. A. Zhevakin), which lead to the appearance of pulsation. In particular in works of B. V. Kukarkin (1964) and J. J. Ikaunieks (1965), a third strip of instability is also noted, positioned in the region of stars of class M and luminosity M_V from 0^m to -3^m, occupied by stars of type Mira Ceti. Perhaps it is connected with structure reconstruction of a star near the upper edge of the branch of giants of spherical and old open clusters. Still higher are red semiregular supergiants like stars in h and χ Per clusters.

To understand the role of variable stars in stellar evolution, first they must be studied in star clusters, which occupies an ever greater place in the works of Soviet astronomers. Variable stars in globular clusters are being studied in Moscow, Kiev and most recently in Sverdlovsk. The work of P. N. Kholopov (1956)

up to the present time remains the main source of information about pulsating variables in open clusters; their study (besides the cepheids) has essentially only begun and promises much of interest.

Eruptive variables. Variables of type RW Aur and related objects. Interest toward these stars sharply increased at the end of the 1940's, when V. A. Ambartsumyan attracted attention to groupings of stars of type RW Aur (T-association), connected with diffuse matter. An extensive investigation of these groupings along with Go Herbig and G. Hard is credited to P. N. Kholopov (1950-1959), who composed the most full list of them. The first large work for the study of the grouping of these stars in the region of the Orion nebula was conducted by P. P. Parenago (1954), who showed the characteristic peculiarities of these groupings. P. N. Kholopov studied also location of these variables on the color-luminosity pattern, revealing a so-called T-band occupied by them. Usually these stars are disposed above and to the right of the main sequence. Rapid irregular changes of brightness, the appearance of emission lines and continuous emission in the spectrum V. A. Ambartsumyan (1954) interpreted as the result of extension on the surface of these variables of prestellar substance, still preserved in their mineral resources. I. M. Gordon (1958, Khar'kov) offered a hypothesis explaining these phenomena by the motion of relativistic electrons in magnetic fields. Facts collected by P. N. Kholopov permitted him to support a widespread point of view in which variables of the class RW Aur are stars who have not yet finished gravitational compression and are moving to the main sequence. This in particular is indicated by their position on diagrams of G-R stellar groupings of different age. In 1963 P. N. Kholopov offered a classification diagram of such stars, which can be examined as an evolutionary sequence. I. G. Kolesnik (1964) investigated the role of convection instability and luminiscence of unbalanced plasma in the appearance of the phenomena of constationarity for these stars. These phenomena can be intimately connected with the existence (according to calculations of Ch. Khayashi) of a deep convection zone for stars who have finished gravitational compression. A theory of flares of variables

of this class is also being developed by V. G. Gorbatskiy and R. Ye. Gershberg. A large role for understanding the nature of these variables is played by cooperative studies. Observations of the brightness of flash variables at the Crimean Astrophysical Observatory, at Odessa and Abastumani, synchronous with radio observations at the Jodrell Bank Observatory (England), led to the detection of flares also in the radio-frequency band, simultaneous with the optical, and permitted an estimation of the energy liberated during the flares in both ranges.

Eruptive variables. Nova and similar objects. Extensive investigations of novae have been made since the 1920's by B. A. Vorontsov-Vel'yaminov, who in particular studied in detail their light curves and showed that in the logarithmic scale they can be represented by segments of lines. He investigated also their spectral peculiarities, the connection of novae with other blue and white stars. E. R. Mustel' investigated expanded shells of novae; he and his pupils made a series of spectrophotometric studies of these stars, studied the physical conditions and chemical composition of the shells.

At Abastumani, Moscow and Dushanbe several novae were found, among them the especially interesting 1956 Nova Ursae Minoris, discovered by V. Satyvaldyyev and possessing unusually great luminosity, amplitude and z-coordinate.

Even in the 1930's Kukarkin and Parenago showed that stars of the type U Gemini are dwarfs The luminosity they found for these stars is confirmed by contemporary investigations.

A fundamental value belongs to the connection between the amplitude of a flare of stars of type U Gemini and the average interval of time between flares, shown even in 1933 by B. V. Kukarkin and P. P. Parenago. Recurrent novae obey also a similar dependence. A study of this dependence and also the luminosity of novae occupied I. M. Kopylov (1955). The amplitude of the flare grows with an increase of the interval of time between flare, and it is not

excluded that such dependences are obeyed also by typical novae. Its important value becomes especially clear in recent years in connection with the discovery in the United States of the remarkable fact that these stars, as also stars of type U Gemini, turn out to be components of close binary systems.

Supernovae. P. G. Kulikovskiy (1944) made the first systematic investigation of light curves of the supernovae of stars, dividing them into four classes. I. S. Shklovskiy, P. P. Parenago and P. N Kholopov (1952) identified with nebulae — sources of radio emission — a series of supernovae, observed in antiquity and in the Middle Ages. Especially much for clarification of the physical nature of gigantic flares of supernovae was done by I. S. Shklovskiy. He indicated a probable connection of supernovae of type II with O—B-stars (1960), carried out a series of works on the study of radio emission of diffuse nebula — remainders of supernovae flares. Yu. P. Pskovskiy studied the frequency of encountering supernovae in galaxies of various types and their luminosity. Parameters of a subsystem of supernovae in our Galaxy were investigated by I. M. Kopylov. R. Ye. Gershbert, L. P. Metik and E. A. Vitricheno (1964) started a check of the hypothesis of Blaauw on a connection of fast O—B-stars with flares of supernovae, presenting numerous arguments in its benefit.

Systematization of information about variable stars, of which (together with those suspected in changeability) there are now nearly 28,000 known, is necessary for work in the study of separate stars and statistical analysis of the totality of information about them; correct selection of classification diagram indicates the direction of investigations, being a working hypothesis about the physical or evolutionary relationship of stars.

In 1948 B. V. Kukarkin and P. P. Parenago with the active help of Yu. I. Yefremov and P. N. Kholopov publishing the first "General Catalog of Variable Stars" (GCVS), containing information about 10,912 objects. In three years these four authors published the "Catalog of Stars Suspected in Changeability." Besides, yearly

supplements to the "General Catalog" were issued. The high quality and completeness of catalog data gave it a wide popularity; references to it can be found in almost every big work on stellar astronomy and stellar physics. A proper order in the designation of new variables was aimed at.

In 1958 Kukarkin, Parenago, Yefremov and Kholopov published a basic work — the second publication of the "General Catalog of Variable Stars," containing information about 14,708 objects and all possible auxiliary tables. In 1960 the "First Supplement" to this publication of the catalog appeared, composed by Kukarkin, Yefremov, Kholopov[1] and containing along with more precise determinations of the 1958 GCVS information about 796 newly designated variables. In 1965 many years of work completed the preparation of the "Second Catalog of Stars Suspected in Changeability" (B. V. Kukarkin, P. N. Kholonov, Yu. N. Yefremov, N. Ye. Kurochkin), containing information on 3905 stars. Work on composition of the "Second Supplement" to the 1958 GCVS was completed. Extensive work on the composition of a third publication of the "General Catalog" has begun, in which the classification of variables (especially the incorrect) will be essentially examined and put into agreement with contemporary ideas about the nature of variable stars. The card bibliographic catalog of variable stars is continuously being supplemented (M. S. Frolov (from 1960), N. P. Kukarkin, V. P. Fedorovich, P. N. Kholopov, Yu. I. Yefremov (to 1960), Yu. N. Yefremov (from 1960) and others), embracing all world literature about these stars and increasing every year by 5000-8000 cards. Work becomes ever more labor consuming, although a considerable part is already conducted with the help of machines.

V. P. Tsesevich and M. S. Kazanasmas created valuable atlases of maps for the environments of variable stars, containing nearly 4000 stars.

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[1]P. P. Parenago died prematurely 5 January 1960.

In this small survey, as already was said, it was possible to stop only on works most urgent from today's point of view. We will now tell briefly the area of work at various observatories of the country.

In Moscow B. V. Kukarkin, his colleagues and pupils along with the composition of catalogs of variable stars continue the investigation of morphological characteristics of intrinsic variables. Under the leadership of P. N. Kholopov on the 70-centimeter reflector at Moscow large-scale photographs of variables — close binaries are being collected, and variables in clusters are being discovered and investigated. Recently it was proven (N. Ye. Kurochkin, P. N. Kholopov and A. S. Sharov) that fast variables in M 67 and NGC 188 are stars of type W Ursae Majoris, but not RR Lyrae. N. Ye. Kurochkin is developing a method of studying variable stars, especially their discovery. The proper motions of variables are under study, and also their space-kinematic characteristics (N. M. Artyukhin, D. K. Karimov, Ye. D. Pavlovskaya).

Variable stars in stellar associations and the environments of clusters are being studied and discovered from photographs of chosen regions of the sky, obtained now on the 40-centimeter astrograph of the Crimean station GAISh. This station along with the Abastumani and Byurakan Observatories from 1961 has made a systematic search for supernovae. So far four supernovae (N. Ye. Kruochkin, G. V. Zaytsev, V. Ye. Yakimov and A. D. Chuadze) have been discovered.

At the Crimean Astrophysical Observatory, the best in the country, the active study of physical characteristics of variables occupies a number of astronomers. From 1963 for spectral observations the 2.6-meter telescope named after G. A. Shayn has been effectively used. Kopylov conducts various investigations connected with the role of variable stars in stellar evolution and their spectral peculiarities. Boyarchuk, and also Belyakin and Bartash study the spectra of eruptive variables. In special detail A. A. Boyarchuk has investigated symbiotic stars and Be stars. Several colleagues of the observatory headed by V. B. Nikonov are conducting intense

electrophotometric observations of eruptive stars and developing new equipment and methods of observation. Among the most interesting results of these observations we must note the detection of fluctuations of brigntness in minimum for stars of type U Gemini (K. K. Chuvayev, 1962) and conclusions from the observations of flare stars. In 1956 Ro Ye. Gershberg and F. F. Chugaynov were able to make unioue simultaneous spectral and photoelectrical observations of nine flares of stars of type UV Ceti with high time resolution. N. M. Shakhovskoy is making a study of polarization of the radiation of variable stars, begun by him in Dushanbe. By the change of polarization with the phase of change of brightness he has proved the appearance of polarization in the atmospheres of a series of stars and estimated the degree of loss of mass during flares of eruptive variables.

In Odessa under the leadership of V. P. Tsesevich continues extensive work on photographic and visual observations of variables, especially the Lyrids (R. Ye. Chuprin, Yu. Ye. Migach and others). Photography of the whole sky is regularly obtained. Numerous active young people have also begun electrophotometric observations. Under the leadership of A. M. Shul'berg eclipsing variables are being investigated. G. A. Lange is making a series of several years of visual observations.

Intense photoelectrical observations are being conducted at Abastumani (Ya. I. Kumsishvili, N. L. Magalashvili). At the same place I. F. Alaniya is making spectral studies of the Lyrids, M. V. Dolidze studies of emission stars and R. A. Bartaya conducts spectrophotometric investigations of eruptive stars. Investigation of young eruptive variables are being conducted at Byurakan (G. S. Badalyan and others). The study of nonstationary stars has been begun at the observatory of the Academy of Sciences of the Azerbaydzhan Soviet Socialist Republic in Pirkuli near Shemakha.

Kiev astronomers are developing a theory of the change of brightness of flare stars (I. G. Kolesnik) and variables of type β Cephei (V. V. Porfir'yev and others). In L'vov under Ya. T. Kapko photographic and photoelectrical observations are being made of variables, especially the cepheids.

The study of red variables of stars and recently their photoelectrical observations are being conducted in Riga under the leadership of Ya. Ya. Ikavnieks. At Vil'nyus irregular and semiregular variables are being studied. At the same place V. L. Stayzhis is developing a new universal photometric system with whose help it will be possible to determine many characteristics of the stars, in particular the variables.

At Tashkent an investigation of stars of type RW Aurigae and related objects is being conducted (I. M. Ishchenko and V. S. Shevchenko). At Dushanbe photographic observations of cepheids and other variables are being conducted (O. P. Vasil'yanovskaya and others).

Visual and photographic observations of the Lyrids are being conducted at Rostov (A. A. Batyrev and others). Photoelectrical observations of eclipsing variables continue at the V. P. Engelhardt Observatory (R. A. Botsula, M. I. Lavrov). Investigations of variable stars are being conducted also at Leningrad, Alma Ata, Kishinev, Sverdlovsk and other places.

In connection with the increase of the number of contemporary instruments our observatories have taken on even more investigations, based on their own high-quality material. New large instruments, entering service at Shemakha and Riga, will be widely used for observations of variable stars. However, two factors still slow our work: sharp deficiency of contemporary laboratory equipment and absence of domestic astronomical photographic plates. Work on photographic photometry which answers contemporary requirements is possible only if there is in this region of the sky a photoelectrical standard of stellar magnitudes. Nonetheless, work on the creation of such standards is not being done here, although now this has become possible. Now, surmounting these deficiencies can be considered the most important problem of not only the researcher in variable stars, but also in general, all astronomers studying stellar astronomy and stellar physics. Work in this direction is being conducted actively. It is necessary to sharply increase the

attention toward investigation of variable stars in stellar groupings and to start such work in other galaxies, for which now possibilities are finally open.

Soviet researchers of variable stars are on the front lines of world science in theoretical works, semi-empirical generalizations, broad cosmogonic conclusions. The time has arrived to reach such a level in the region of observations as well.

Our international communications grow and strengthen. A number of Soviet astronomers (B. V. Kukarkin, D. Ya. Martynov, V. B. Nikonov, P. P. Parenago, P. N. Kholopov, V. P. Tsesevich) have already been or are now in charge of the commission of the International Astronomical Union connected with the investigation of variable stars. Wide possibilities for contacts with foreign astronomers appear in connection with publication of catalogs of variable stars. Our catalogs are used by astronomers the world over. Their contents and the system of classification of variable stars utilized in them are discussed and always highly valued by the Commission for Variable Stars of the International Astronomical Union. V. P. Tsesevich participates in composition of the epheremides of eclipsing variables and Lyrids, issued yearly.

Many astronomers of socialist countries have studied variable stars at observatories of our country. The opposite cases unfortunately are not numerous. We insufficiently participate in international conferences.

Conferences conducted in recent years by the Commission for Variable Stars of the Astronomical Council of the Academy of Sciences, USSR (14th plenum of the Commission, dedicated to cepheids and stars of the class RW Aur, L'vov, 1963; symposium "Variable Stars and Stellar Evolution," M., 1964; Odessa Conference on Coordination of Investigations of Variables, 1965; 15th plenum of the Commission, dedicated to variables in stellar groupings and eclipsing variables, Sverdlovsk 1966), orient the Soviet researchers of variable stars on the most pressing and long-term problems. These conferences

especially convincingly showed the necessity of thorough and active investigation of variable stars, as stars on critical stages of evolution and presenting special interest for the solution of the most various problems of stellar physics and stellar astronomy.

Instead of the few persons in our country occupied with variable stars 50 years ago, now there are over 60 astronomers actively working in this region; their contribution to world science is universally recognized. There is no doubt that the most interesting problems of variable stars before Soviet researchers will be successfully solved and we will approach still closer to an understanding of the origin and evolution of stars and structure of the stellar systems.

ECLIPSING VARIABLES

By studying eclipsing variables we can obtain the most various information about the nature of stars. Eclipsing variables are the source of our knowledge about absolute dimensions and masses of stars, make it possible to judge about the structure of their atmospheres and mineral resources, permit studying relative motion and interaction of the components of close stellar pairs and, finally, supply us data of cosmogonic character.

Prior to the October Revolution in Russia as also in other countries the study of eclipsing variables had only started. Observations were in most cases visual. The theory of eclipsing variables took its first steps. The same position in this region of astronomy was preserved in the first years of Soviet power.

The story of Soviet investigations of eclipsing variables essentially starts in the middle 1920's. Since then methods of observations of these stars continuously improved and theory was developed.

An outstanding role in development of the study of eclipsing variables in the USSR was played by the Kazan school of "transitionists," which appeared near the end of the 1920's in the Engelhardt Astronomical Observatory at Kazan University. Its founder and leader during the period of more than a quarter of a century was D. Ya. Martynov.

For 40 years (from 1927) at the Engelhardt Observatory many photographic, colorimetric, spectrophotometric and, in the postwar period, photoelectrical series of observations of many tens of variable stars were conducted.

Let us note here the studies of the stars U Cephei and U Sagittae (N. I. Chudovichev, 1939, 1943), δ Librae and λ Tauri (V. A. Krat, 1938, 1944), RX Cassiopeiae and RU Monoceratic (D. Ya. Martynov, 1955), MR Cygni and TT Auriga (M. I. Lavrov, 1965), 32 Cygni (R. A. Botsula, 1962).

An essential contribution in the studies of eclipsing variables was made by scientists of the Abastumani Astrophysical Observatory. In the middle of the 1930's V. B. Nikonov set up the first photoelectrical observations of eclipsing variables in the Soviet Union. They are still being carried out under the leadership of N. L. Magalashvili. At observatories exact photoelectrical curves of many eclipsing variables are obtained and solved, including λ Tauri, δ Scuti, 44 i Boötis (V. B. Nikonov), U Ophiuchi, V 505 Sagittae, Y Cygni and α Virginis (N. L. Magalashvili, I. L. Kumsishvili, 1962, 1964) and others.

Many observations of eclipsing variables were made at the Tashkent Astronomical Observatory in the postwar period of I. M. Ishchenko. They made photometric studies of Z Draconis (1947) and obtained photographic light curves of more than ten eclipsing variables (for example, CQ Cephei, MR Cygni, RT Lacertae) (1963).

A large number of eclipsing variables was investigated at the Crimean Astrophysical Observatory by S. V. Nekrasova. She obtained photographic light curves of several stars (SV Camelopardalis, XZ Canis Majoris and others) and made polychromatic photoelectrical studies of β Lyrae and AN Cephei (1960). It is necessary to note the detailed spectrophotometric study of ζ Aurigae by R. N. Kumaygorodskaya and I. M. Kopylov (1963), and also the trichromatic photoelectrical observations of SQ Cephei, conducted by P. Ye. Chugaynov (1960).

Observations of eclipsing variables and treatment of observations were conducted also at other observatories. Thus, at the Pulkovo Observatory N. M. Gol'dberg-Rogozinskaya (1951, 1956) made a spectrophotometric study of U Herculis and RS Vulpeculae. At the Astronomical Observatory in Tartu photographic and photoelectrical photometry of eclipsing variables occupied Kh. Albo (1958, 1960, 1964). At the Odessa Observatory K. Kh. Saidov studied β Lyrae using an objective prism. Later serious photoelectrical and spectrophotometric investigations of RZ Scuti were carried out there by V. G. Karetnikov. In recent years at Odessa photoelectrical observations of variables have been set up (Yu. A. Medvedev, N. A. Mis'kin). Good photoelectrical curves of a series of variables have been obtained (RZ Cassiopeiae, KR Cygni and others). At the young Shemakhinskiy Astrophysical Observatory S. M. Azimov (1962) has made spectrophotometric studies of several eclipsing variables (U Cephei, U Sagittae and others).

It is difficult to name an astronomical observatory in the Soviet Union where at some time observations of eclipsing variables to determine their periods or changes of periods have not been conducted. A huge number of such observations has been carried out starting with the 1920's by V. P. Tsesevich, G. A. Lange (Odessa), A. V. Solov'yev (Dushanbe). A multitude of observations has been conducted and continue still at the observatories of Odessa, Kazan, Rostov-on-Don, L'vov, Tashkent, Tartu (Tyravere), Moscow.

This brief survey of the studies of eclipsing variables was somewhat artificially divided into two parts: observation and theoretical. The first part is completed, let us turn to the second — theoretical research.

In 1912-1913 in the United States a series of articles emerged by G. N. Russel and H. Shapley which set forth the authors' method of calculating the photometric orbits of eclipsing variables. The work of Russel and Shapley played an outstanding role in development of the theory of these stars, but with an increase of the accuracy of observations the use of their method gives less and less

satisfactory results. At the same time (1912) in Russia an important work by S. N. Blazhko appeared "Algol-type stars," which first examined the question of limb darkening of the stellar disks of stars composing eclipsing pairs. These investigations exhaust the list of works on the theory of eclipsing variables which existed at the beginning of the 1920's. (Earlier works we do not consider, since their results are covered by the enumerated investigations.)

Development of the theory of variables in the Soviet Union consisted mainly in improvement of the method of determining the elements of photometric orbits (including creation of high-accuracy tables for calculation of these elements) in the investigation of subtle effects, in the development of the question about figures of equilibrium of the components of close pairs, in study of the changes of periods of eclipsing variables and establishing the causes of these changes and, finally, in many numerical statistical investigations. In the second half of the examined period here even more attention is allotted to obtaining physical characteristics of the stellar atmospheres on the basis of analysis of light curves of eclipsing variables.

The first research on the theory of eclipsing variables in Soviet time was the 1924 article of S. B. Sharbe, in which he gave a simple method of determining the orbital elements of Algol-type stars. At the present time Sharbe's method can be used for obtaining preliminary values $K = r_2/r_1$ (r_1 and r_2 -- radii of components of eclipsing system).

In the number of first works on the theory of eclipsing variables it is necessary to note also the study of RU Monocerotis published by A. D. Dubyago and D. Ya. Martynov in 1929. Extending Russel's method to a system with strongly elliptic orbits, the authors found elements of the photometric orbit of RU Monocerotis and showed a fast rotation of the line of apses. As it is known, knowledge of the speed of rotation of the line of apses permits judging the distribution of density inside the star. This circumstance impelled D. Ya. Martynov to conduct a new, photoelectrical investigation of

RU Monocerotis (1965). He obtained more exact data about rotation of the line of apses and accordingly about distribution of substance inside the star.

In the mid-1930's V. A. Krat came forward with a series of articles in which he gave a modification of Russel's method.

V. P. Tsesevich (1939, 1940) published a table for determining the orbital elements of Algol-type eclipsing stars. These tables, in the opinion of D. Ya. Martynov, constitute the biggest contribution of Soviet astronomy to the problem of determinating orbital elements of eclipsing variables.

Tsesevich's tables are still used here and abroad both for calculation of orbital elements and for the construction of other tables.

To V. P. Tsesevich belongs the merit of using (1941-1944) the method of differential corrections for calculating orbital elements. Being, in our opinion, one of the best methods of determining orbits, Tsesevich's method is especially convenient when calculation can be done by electronic computers.

In the middle 1940's the development of classical methods of determining the orbits of eclipsing variables was basically completed. In literature a huge quantity of material was accumulated which needed systematization and critical survey. This extensive work was done by V. P. Tsesevich and D. Ya. Martynov. It made up the greater part of the third volume of the collective monograph "Variable Stars" (see M. S. Zverev and others, 1947). In the third volume a critical account is given of different methods of determining orbital elements of eclipsing variables, both spheric and ellipsoidal. At the end of the volume are placed Tsesevich's tables. There are no similar books to this third volume.

Here it is appropriate to indicate two more valuable works on eclipsing variables: first, a monograph by D. Ya. Martynov

"Eclipsing Variables" ("Variable Stars," Vol. II, 1939) and secondly, Chapter 5 "Photometric Binary Stars" ("Course in Astrophysics and Stellar Astronomy," Vol. II, edited by A. A. Mikhaylov, 1962). In his monograph D. Ya. Martynov gave a splendid survey of the theory of eclipsing according to the state in 1939 and placed in it a series of original statistical investigations. Martynou's book is still used. An article of V. A. Krat gives in condensed form (all on three printer's sheets) the theory of eclipsing variables. The chapter presents great interest for specialists.

Together with development of the method of determining orbital elements, an intense study of the figures of equilibrium of components of close binary systems was conducted in our country. Especially valuable work on this subject was done by V. A. Krat (1937), who summarized them in the monograph "Figures of Equilibrium of Celestial Bodies," appearing in 1950. V. A. Krat also carried out a large number of studies on determining the limb darkening of stellar disks from observations of eclipsing variables. He offered a method of determining the coefficient of darkening on the basis of analysis of the light curve. Tsesevich solved this problem using the method of differential corrections. A serious investigation of the center-edge effect for eclipsing variables with an evaluation of different methods of determining the coefficient of darkening was published by N. N. Semenova (1958). The existence of methods of determining coefficients of darkening from light curves of eclipsing variables permits checking the validity of theoretical models of the atmospheres of stars of various spectral classes.

In the middle 1940's it was clarified that there exists a great deal of eclipsing binary systems for whose components it is possible to assume the presence of extended atmospheres. The light curves of such stars cannot be determined for any values at all of the coefficient of darkening. At the same time A. M. Shul'berg (1947) published his method of determining orbital elements of Algol-type variables with extended atmospheres and calculated tables needed for solving this problem. The value of the tables is determined also by the fact that tney can be used with any law of limb darkening.

Using his own method, Shul'berg (1953, 1961, 1962) found orbital elements of several eclipsing variables (SX Cassiopeiae, V444 Cygni, UX Monocerotis and others).

Eclipsing variables with extended atmospheres were also studied by F. I. Lukatskaya in the 1950's (1952, 1954) at the Main Astronomical Observatory of the Academy of Sciences of the Ukrainian SSR. Later she was joined by A. I. Rubashevskiy. Using their own method of determining light curves in the case of atmospheric eclipse, they obtained orbital elements of RT Andromedae, SX Cassiopeiae, RX Gemini and AW Pegasi (F. I. Lukatskaya, A. A. Rubashevskiy, 1961).

In general, the attention of many researchers in eclipsing variables in the 1950's was attracted by systems with the phenomena of nonstationarity. According to an idea of O. L. Struve, components of certain of the closest binaries must eject streams of substance. These streams, depending upon initial conditions, can form envelopes, disperse and, finally, transfer substance from one star to another. In all cases equilibrium motion is disturbed – the phenomena of nonstationarity appear.

In the Soviet Union these phenomena have been studied by many astronomers. Thus, for example, M. A. Svechnikov could explain the change of periods of several eclipsing binaries (U Cephei, RZ Cassiopeiae, U Saggitae and others) as the result of ejection of substance by components of these systems. A. N. Dadayev (1954) published a larger study of a series of eclipsing binaries, in which he assumes the presence of gas streams. N. M. Gol'dberg-Rogozinskaya, A. V. Sofronitskiy, K. Kalchayev also investigated similar systems.

In connection with this it is necessary to note earlier works of V. A. Krat and D. Ya. Martynov, who independently examined the influence of ejection of substance on the development of close binaries. They showed that a decrease of angular momentum plays a large role in the evolution of binary systems; in particular, it causes changes of the periods of eclipsing variables.

Extensive work based on data about the variability of periods of 58 eclipsing systems was carried out by A. Ye. Prikhod'ko (1961) at Odessa. The author arrives at the conclusion that the changes of periods are best explained by the assumption of transfer of matter from one star to another.

Ejection of matter is not the only cause of a change in the periods of eclipsing variables. For example, we know that for Algol the period changes due to the perturbing action of a third star which is a member of the Algol system. Long before this fact was established, in the mid-1930's the hypothesis of the existence of a third body for certain eclipsing systems was developed in detail by D. Ya. Martynov. To solve the problem the author had to use the complex celestial-mechanical theory of the moon's motion.

Recently in the USSR attempts were undertaken to determine the orbital elements of eclipsing variables using electronic computers (V. M. Tabachnik, A. M. Shul'berg, 1965). The first positive results have been obtained. During 1966 V. M. Tabachnik completely developed a method of determining the orbits and coefficient of darkening of eclipsing Algol-type variables with circular orbits on an electronic computer.

In 1932 at the Engelhardt Astronomical Observatory under the leadership of D. Ya. Martynov and V. A. Krat the composition of a card bibliographic catalog of all eclipsing variables began. Work on the catalog is still being conducted. It contains more than 40,000 bibliographic references, and naturally is of huge value.

Materials of the catalog have been the subject of different statistical investigations. Thus, D. Ya. Martynov (1937) discovered a connection between period and spectrum for eclipsing variables; V. A. Krat (1944) developed a detailed classification of eclipsing variables; N. I. Chudovichev (1952) composed the most complete catalog of the orbital elements of eclipsing variables; M. I. Lavrov (1953) conducted work on certain statistical regularities for eclipsing variables, etc.

In conclusion of our short survey it is necessary to say that in the Soviet Union after 50 years considerable successes have been attained in the study of eclipsing variables. Results of investigations of Soviet scientists in this region of astronomy present a valuable contribution to world science.

STELLAR PHYSICS

Astrophysics at present is the most extensive and rapidly expanding area of astronomy. The most important role in it belongs to the study of stellar physics. It is based on data obtained from the observations of stellar radiation. The radiation which can be sensed is very weak, and high-quality observations require powerful telescopes. Soviet observatories, with few exceptions did not have such tools for a long time, and only in the last decade have large telescopes been set up in several observatories. Therefore in works on stellar physics conducted in the USSR the main place is occupied by theoretical research. Great successes were attained in the solution of a series of problems in stellar physics, for example in the transport theory of radiation in the stellar atmospheres and in the physics of nonstationary stars. They are connected in the first place with the work of V. A. Ambartsumyan and V. V. Sobolev, who obtained wide fame both in the USSR and abroad.

Astrophysics in the USSR expanded especially intensively in postwar years. Activity of the old scientific centers in Leningrad and Moscow expanded, large astrophysical observatories in the Crimea and Armenia were built. Theoretical research on stellar physics began in many scientific establishments of the country. For contemporary astrophysics an ever-increasing necessity of the coordination of efforts of theoreticians and observers is especially characteristic.

Stationary Stars

Observations

In the first stages of development of astrophysics a considerable place in the observations of stars was occupied by the determination of their color. On the assumption that a star radiates as an ideal black body, by the color of a star the temperature of its surface can be found. Numerous works on determination of the colors of stars and investigation of the influence of different factors on the color of a star were carried out by G. A. Tikhov (1924, Pulkovo) and V. G. Fresenkov (1929). Subsequently results of colorimetric works began to be used chiefly in stellar astronomy, and therefore they are dealt with in greater detail in the corresponding chapter.

Incomparably more complete information about the study of stars and the structure of their external layers is given by spectrophotometry. Inasmuch as during these investigations the spectra must have large dispersion, and the necessary equipment for producing such spectra in the 1920's and 1930's was only at the Simeiz Observatory (40-inch telescope) and at Pulkovo, spectrophotometric studies initially were made mainly at these places.

Spectrophotometry of stars was the subject of a very great number of works by G. A. Shayn (1892-1956), carried out basically at Simeiz from 1924. He studied the lines of magnesium, sodium and calcium in stellar spectra and examined the influence of absorption lines on the brightness and color of stars. G. A. Shayn (1934) jointly with the American astronomer O. Struve developed a method for determining the speed of rotation of stars by the profiles of absorption lines in their spectra and found the value of this speed for a series of stars. In collaboration with V. F. Gaze (see V. F. Gaze, G. A. Shayn, 1948) he investigated the spectra of stars with very great amounts of carbon in the atmospheres. Considerable interest in connection with the study of nuclear reactions in stars was presented by determination of the isotopic abundance of the carbon isotope C^{13} with respect to C^{12} in the atmospheres of stars of class N (G. A. Shayn, 1942). It turned out to exceed

by a factor of several tens the amount on earth. At Simeiz the structure of molecular bands in the spectra of stars of late classes (P. P. Dobronravin, 1950) was also studied.

Investigations of the spectra of stars at Pulkovo Observatory were started long before the revolution by A. A. Belopol'skiy. These works were continued by him and his colleagues even after 1917, but pertained basically to nonstationary stars (they are dealt with later). Later O. A. Mel'nikov (1954) organized the observation of the spectra of stars of early classes in mountain conditions, which permitted especially thorough study of the ultraviolet region of the spectrum. He offered a new method for determining the zero-point on the scale of spectrophotometric temperatures. Besides the continuous spectrum for these stars their line spectrum (O. A. Mel'nikov, 1954) was also photometrically studied. Using the obtained profiles of absorption lines characteristics of conditions in the atmospheres of stars were obtained (electron pressure, acceleration due to gravity).

In 1952 investigations began at the new, well-equipped Crimean Astrophysical Observatory. There stellar spectra were actively studied. The possibilities of observation especially increased after the introduction of a telescope with a 260-cm mirror diameter to the number of operational instruments. This section is too short to illustrate all the work of the Crimean Observatory on the study of stellar spectra. The basic direction of investigations was determination of physical conditions in the atmospheres of stars of early classes and the chemical composition of the atmospheres.

In 1954-1955 E. R. Mustel' and L. S. Galkin conducted a series of works on the spectrophotometry of peculiar and "metallic" stars of class A. These are stars for which the lines of certain elements (in the second case of metals) strongly differ in intensity from corresponding lines in the spectra of usual stars of class A. They showed that the cause of such distinction is not so much special conditions of ionization and excitation of atoms of some elements in the atmospheres of these stars as a real deviation of the chemical

composition of their atmospheres from the composition of usual stars.

During the study of the spectra of stars of class O, taken with large dispersion, I. M. Kopylov (1956) found that the observed equivalent widths of spectral lines for stars of this class is essentially affected by the intermolecular electrical fields (effect of Stark splitting of lines, found by foreign researchers in the spectra of stars of other classes even in the 1930's). On the basis of the study of the investigation equivalent width of lines he made a quantitative spectral classification of a great number of stars (1960). At the Crimean Observatory work was also conducted on the spectrophotometry of stars of classes Of and F and physical conditions in the atmospheres of these stars were determined. From spectrograms taken with very high dispersion A. A. Boyarchuk studied in detail the spectrum of Sirius, enabling a highly accurate determination of the structure of the atmosphere of this star.

In the 1950's research in the spectrophotometry of stars of early classes was also expanded at the Byurakan Observatory (L. V. Mirzoyan, 1953; N. L. Ivanov, M. A. Arakelyan, 1957).

In contemporary observations of stars an important place is occupied by the investigation of their brightness and color by photoelectrical methods. In the development of these methods in the USSR a large role was played by the work of V. B. Nikonov (Abastumani, KrAO). In 1953, in particular, he put together a catalog of photoelectrical color equivalents of stars of early spectral classes. Subsequently photoelectrical methods widely were used at the Abastumani Observatory in the study of variables, and also at the Crimean and Byurakan Observatories.

During determination of the chemical composition of stellar atmospheres and conditions existing in them by the observable dependence equivalent line width on number of absorbing atoms (growth curves), it is necessary to know the forces of the oscillators for corresponding atomic transitions. Laboratory determinations of the

forces of oscillators were made at Pulkovo for iron, chromium and titanium (L. A. Mitrofanova, 1953, 1954, 1955) and at the Crimean Observatory for a number of atoms (M. Z. Khokhlov, 1963). A large number of forces of oscillators was obtained in 1960 on the basis of study of stellar spectra (M. Ye. Boyarchuk, A. A. Boyarchuk). We will not stop on the numerous works done on the solar spectrum at the Pulkovo and Crimean Observatories and others. They are described in the section titled "the sun."

Theory of Atmospheres

The only source of information about conditions existing in the external layers of a star, and about the structure of these layers is the radiation from them. The relationship of intensities of radiation in different wavelengths, characterizing the spectrum of a star, is determined by the processes of radiation transfer. Therefore theoretical research on the external layers of stars is inseparably connected with the development of problems on radiation transfer.

During the study of stationary stars usually it is assumed that radiative equilibrium exists in their atmospheres, i.e., the total volume unit of energy which can be radiated is equal to the energy absorbed in that same volume. Under this condition the problem about energy transfer reduces to an integral equation. The solution of the equation determines the so-called function of the source, with the help of which the intensity of radiation is found in each point of the medium and on its edges. These equations were solved approximately for a long time.

V. A. Ambartsumyan in a series of works published in the 1940's proposed a new, very effective means for finding directly the intensity of radiation from the medium after multiple scattering (this is an observable quantity). Functional equations were composed on the basis of V. A. Ambartsumyan's (1943) "principle of invariance," which later obtained wide application not only in astrophysics, but also in different regions of mathematical physics. These functional equations are comparatively easy to solve.

The search for new effective methods of solving problems in the theory of radiation transfer was successfully continued by V. V. Sobolev. In 1949 he offered a method for composing integral equations for the intensity of radiation coming out of a medium, and solved these equations in evident form for a medium of infinitely great optical depth. An especially important step in the development of a transfer theory proposed by V. V. Sobolev (1951) was the probabilistic method, founded on determination of the probability of an output of light quantum from a medium. Results of the work of Sobolev on the theory of radiation transfer, carried out prior to 1956, are contained in his monograph "The Transfer of Radiant Energy in the Atmospheres of the Stars and Planets" (1956). Later he found a method for solving integral equations of the theory of multiple scattering, with the help of which both the intensity of outgoing radiation and the field of radiation inside a medium can be found. The method was used for the exact solution of the integral transport equation of radiation in frequencies of a continuous spectrum in the case of a semi-infinite medium (V. V. Sobolev, 1959). Precise asymptotic solutions for an optically thick layer were also shown (V. V. Sobolev, 1964).

Resolution of the problem about radiation transfer in the external layers of a star permits determining its theoretical spectrum. The distribution of energy of a continuous spectrum depends on the structure of the external layers, on how temperature and pressure change with depth. By comparing spectra calculated for various models of the atmospheres with observed spectra, parameters of the atmosphere of a star can be found and its structure can be determined.

To solve the problem about radiation transfer it is necessary to know the expression for the coefficient absorption, determining the optical properties of the medium. In a complex way it depends on the frequency of radiation, chemical composition of the gas, its temperature and density. At a sufficiently high temperature ($T > 10,000^{\circ}$) one may assume that opacity is caused by hydrogen. The expression for the coefficient of absorption then is essentially simplified. The theory of radiation equilibrium of the photospheres

of hot stars (with effective temperatures from 10,000 to 20,000°) during the calculation of the dependence of the coefficient of absorption on frequency was built in the P. K. Shterneberg State Astronomical Institute by E. R. Mustelem (1940). He obtained the distribution of energy in spectra of stars, very strongly differing from Plank distribution and corresponding well to that observed.

For different questions of astrophysics the group of so-called white dwarfs is of great interest. These are stars of extraordinarily great density. The spectra of white dwarfs possess a series of peculiarities as compared to the spectra of other stars. At the Leningrad University the theory of the photospheres of these stars was developed and their continuous spectrum successfully interpreted (A. K. Kolesov, 1964). At the Tartu Observatory A. Sanar and I. Kuuzik calculated models of the atmospheres of very hot stars, corresponding to nuclei of planetary nebulae.

Recently successes have also been attained in the study of the structure of photospheres of stars of late classes, for which in the absorption of radiation an important role is played by atoms and molecules of metal. The continuous spectrum of a star with low effective temperature considering radiation absorption by metals and TiO molecules was calculated by V. G. Buslavskiy (1964). In all these works the stellar photosphere was considered nonextended, i.e., its thickness was considered small as compared to the radius of the star.

The problem about radiation equilibrium of an extended atmosphere was examined at Pulkovo even in 1935 by N. A. Kozyrev. However, at that time the solution of similar problems did not consider the dependence of the coefficient of absorption on frequency, which, as subsequent investigations showed, played a very important role in the problem of radiation equilibrium of stellar atmospheres.

In the photospheres of hot stars hydrogen, which in amount is a predominant element, is in the ionized state, and therefore the concentration of free electrons is great. In such a case a certain

role in radiation transfer can be played by the scattering on free electrons. The influence of this process on the observed continuous spectrum of stars was first examined by V. A. Ambartsumyan (1938). Later the problem of radiation transfer in a flat layer considering electron scattering and true absorption was solved, and it was shown in particular that electron scattering leads to a lowering of the observed spectrophotometric temperature of the star (S. G. Slyusarev, 1954).

During scattering on free electrons radiation is polarized. Radiation transfer considering polarization was investigated by V. V. Sobolev (1949). Simultaneously this problem was independently solved in the United States by S. Chandrasekar. The degree of polarization of radiation from particular parts of the disk of a star possessing a scattering atmosphere was calculated. In integral radiation of a star polarization can appear if the observed region of the atmosphere is not symmetric spherically, for example, during an eclipse of part of the disk. The effect of polarization later was revealed during the observations of eclipsing variables. At the same time polarization of the light of certain stars which are not eclipsing variables was discovered by V. A. Dombrovskiy (1949) and independently in that same year by W. Hiltner and J. Hall in the United States. This discovery was of great value to many problems in astrophysics.

The most external layers of a star — the atmosphere — radiate little in continuous spectrum. In them spectral lines are formed. The theory of line profiles makes it possible to determine the structure of the stellar atmosphere by the observed profiles and therefore is one of the most important problems in stellar physics. Soviet astrophysicists have attained great successes in the development of the theory of line profiles considering frequency shift of quantum in the scattering process. In solving problems about multiple scattering of radiation in a line frequency shift for a long time could not be considered due to the absence of effective methods of solving the corresponding equations. Exact solutions to the problem of determination of the absorption line profile were

obtained by V. V. Sobolev (1949), who assumed the absence of a relationship between quantum frequencies before and after scattering.

Methods developed by V. V. Sobolev also found application in the theory of formation of radiation lines appearing in the external layers of stellar atmospheres. This problem became very urgent in connection with the successes of extra-atmospheric astronomy (see the section "Space Research..."), making it possible to obtain the first information about resonance radiation lines lying in the far ultraviolet region of the spectrum. On the basis of exact theory V. V. Ivanov (1962, 1963) calculated profiles of resonance lines. He also obtained different simple expressions and composed tables allowing fairly easy location of the solution of a number of problems connected with the formation of these lines (in chromosphere and coronas of stars and sun).

There exist stars possessing a strong magnetic field which influences the observed spectral lines. Radiation transfer in a line considering the presence of a magnetic field was examined by V. Ye. Stepanov (1958), and in 1962 and later by D. N. Rachkovskiy (1964). Results of theory were used for calculation of the equivalent width of absorption lines generated in the presence of a magnetic field (A. A. Boyarchuk, Yu. S. Yefimov, V. Ye. Stepanov 1960).

Results of the investigations of Soviet and foreign astrophysicists on the theory of atmospheres of stationary stars are set forth in detail in the monograph of E. R. Mustel "Stellar Atmospheres" (1960).

Nonstationary Stars

Observations

Stars with bright lines in the spectrum are usually called nonstationary, since they are characterized by fast changes of brightness and spectrum, indicating stormy processes in external layers of the star. As a result of such processes substance is ejected by the star. The ejected substance forms an envelope around

the star in which the bright lines of the spectrum are formed.

The great variety and huge scale of phenomena observed for nonstationary stars and the speed of transitions of stars from one state to another make these objects extraordinarily important for the investigation of structure and evolution of stars. Therefore the study of nonstationary stars occupied one of the main places in Soviet astrophysics during the period of its development, although such stars compose a small part of the total number of stars.

Observations of the changes in brightness of nonstationary stars are presented in detail in the section "Intrinsic Variables." Here we will stop mainly on observations of spectra. Attention of observers was first attracted to the bright lines in spectra as a distinctive peculiarity of these stars. Radiation in lines should affect the brightness and color of a star, which in turn can be used for determination of its temperature and radius. Even in 1935 B. A. Vorontsov-Vel'yaminov estimated the influence of the bright bands on brightness of novae and Wolf-Rayet stars (WR) (B. A. Vorontsov-Vel'yaminov, 1935). In 1946 he investigated the distribution of energy in the continuous spectrum of WR stars and established that it corresponds to a much lower temperature than the effective temperature of these stars. The temperature of WR stars as determined by B. A. Vorontsov-Vel'yaminov (1958) by the bright lines (Zanstra method) turned out to be higher then the spectrophotometric temperatures, and depending on the ionization potential of that ion by which the examined lines are radiated. Subsequent investigations of many authors confirmed these conclusions. B. A. Vorontsov-Vel'yaminov also made numerous investigations of brightness and spectra of novae, results of which along with results of other authors are in the extensive monograph "Gaseous Nebulae and Novae" (1948).

Observations of the spectra of novae using comparatively large instruments were conducted at Pulkovo Observatory (Nova Aquilae 1918), Simeiz (Nova Herculis 1934), Crimean Observatory (Nova Herculis 1960) and the Byurakan Observatory.

One of the most numerous groups of nonstationary stars is long-period variables. In their spectra in a defined epoch appear bright lines whose intensity and profiles periodically change together with a change of brightness. Relative intensities of bright hydrogen lines (Balmer decrement) for them strongly differ from those observed in the spectra of planetary nebulae and nonstationary stars of other types. G. A. Shayn (1935) showed that anomalies in intensities of bright hydrogen lines in the spectra of long-period variables are caused by partial absorption of radiation in corresponding frequencies by molecular compounds located in layers more remote from the center of the star than the region of formation of bright lines. In 1947 G. A. Shayn studied peculiarities of bright lines in the spectra of these stars belonging to neutral and ionized atoms of iron. As a result it was determined that gases move in the atmospheres of these stars toward the outside, which creates the effect of apparent approach of stars to the observer (G. A. Shayn, 1945). This was of great value for subsequent development of the theory of long-period variables.

A considerable number of works was dedicated to the study of stars of class B with bright lines in the spectrum (stars of type Be). Spectrophotome try of the continuous spectrum of stars of type Be and comparison with spectra of stars of class B were carried out in 1956 by Tsoy Dyay O [Translator's Note: transliteration from Russian spelling — Цой Дяй О] (Korean astrophysicist studying at Leningrad University), O. D. Dokuchayeva, M. V. Dolidze (1955), I. D. Kupo, and in 1963 R. Kh. Oganesyan. Investigation of the continuous spectrum of stars of type Be confirmed and definitized earlier conclusions made in France by D. Barbier, D. Chalonge and others that spectrophotometric temperatures of these stars is considerably lower than for B stars of the corresponding subclass, and the jump of radiation intensity near the limit of the Balmer series is also decreased. This result served subsequently as a basis for theoretical interpretation of the spectrum of Be-type stars.

The line spectrum of Be-type stars was investigated at the

Crimean Observatory by A. A. Boyarchuk (1957). He determined the equivalent width of the lines and showed that the optical thickness of envelopes of Be-type stars in lines of the Balmer series is great. The chemical composition of the envelopes of Be-type stars was also compared with the composition of atmospheres of stars in class B (A. A. Boyarchuk, 1957), which demonstrated the absence of essential distinctions between B and Be stars in this respect.

Among Be-type stars the brightest is the star γ Cassiopeia, which in 1936-1940 experienced strong changes of brightness and spectrum. In many countries, including the USSR, the attention of observers was attracted to this star. Detailed description of the changes of its spectrum was given by V. F. Gaze (1947). Systematic observations of γ Cassiopeia continue in Crimean observatory during series of years.

Besides nonstationary stars of these types other stars were actively studied in the USSR. For α^2 Canes Venatici stars there are interesting changes in the spectrum, characterized by intense lines of rare-earth elements. They were studied in detail at the Pulkovo observatory by A. A. Belopol'skiy (1928), and later by others. At the same observatory O. A. Mel'nikov (1950) investigated in detail the spectra of cepheids, which, in particular, made it possible to determine the chemical composition of atmospheres of the cepheids, and also to make conclusions concerning the presence of turbulence in them.

All stars mentioned above have strong luminosity. Development of the technology of observations made it possible in last decade to proceed to the study of nonstationary stars of low luminosity, which include first stars of types T Tauri and UV Ceti. Spectra of stars of these types were studied at the Byurakan Observatory (L. V. Mirzoyan, M. A. Arakelyan). An important peculiarity of spectra in periods of flares is the presence of "continuous emission," covering the absorption spectrum of the star.

Observations of nonstationary stars at the Crimean Observatory

began to expand essentially after the introduction of the 2.6-meter telescope. On it a series of important works already have been carried out. Thus, E. R. Mustel' and A. A. Boyarchuk (1965) studied the spectrum of the "former" nova V603 Aquilae, which flared in 1918. Results of determination of characteristics of this star and its envelope present interest for clarification of the nature of flares of novae. Unique observations of the spectrum and brightness of the star AD Leonis (UV Ceti type) during its flare were conducted by G. Ye. Gershberg and P. F. Chugaynov (1960). A. A. Boyarchuk, investigating the spectra of so-called symbiotic stars, which simultaneously possess peculiarities characteristic for both cold and hot stars — Z Andromedae, AG Draconis and others — found that the unusual appearance of these spectra is explained by the duality of the stars.

Among other observation works one should mention investigations started at the end of the fifties, of polarization of the light of stars at the Byurakan (K. A. Grigoryan and others) and Crimean observatories (N. M. Shakhovskaya, 1963). At the Abastumani Observatory searches were made for stars with a bright line H_α in spectra (M. V. Dolidze, 1959), and other spectral investigations of nonstationary stars.

Theory of Envelopes of Nonstationary Stars

Soviet astrophysicists achieved great successes in the theoretical research of nonstationary stars. Problems connected with nonstationary stars save the first theoretical development only in the 1930's, and one of the first works in world literature in this area was carried out by V. A. Ambartsumyan, who examined the glow of envelopes surrounding hot stars. In the envelopes shortwave radiation of the stars is processed. It ionizes atoms in the envelope, then as a result of recombinations it radiates a quantum of smaller energy in both continuous spectrum and line frequencies. Envelopes of novae on late stages of development are similar to planetary nebulae. They are transparent for radiation in lines of subordinate series, and ionization of atoms in them occurs only

from the ground state. In envelopes of small radius, examined by V. A. Ambartsumyan (1935), it is also necessary to consider ionization from excited states. Therefore investigations of radiation processing in them are much more complex than in the case of planetary nebulae. To facilitate the problem it was accepted that an envelope consists of fictitious atoms with three levels. In the case of an envelope consisting of real atoms with an infinite number of levels, the problem of determining the glow from the envelope reduces to the solution of a complex system of integro-differential equations.

The envelope of a nonstationary star usually moves in relation to the star, while the speed of the envelope is great as compared to the speed of thermal motion of the components of its atoms. At a sufficiently great velocity gradient quanta in line frequencies appearing in the internal parts of the envelope leave the envelope after a comparatively small number of scatterings. The problem of radiation equilibrium in this case leads to the solution of a system of algebraic equations.

The theory of radiation equilibrium of moving envelopes was developed by V. V. Sobolev, who considered the problem for a moving medium in general form, but who also determined the glow of envelopes of different types of nonstationary stars. Basic results of theory are in his book "Moving Stellar Envelopes" (1947).

The theory of moving stellar envelopes explained not only the general character of continuous and line spectra of nonstationary stars, but also peculiarities of the spectra of stars of separate types. A comparatively complete interpretation on the basis of the theory of moving envelopes was given to spectra of Be-type stars. V. G. Gorbatskiy (1949) examined changes of the continuous spectrum of the brightest and therefore well-studied star of this type — γ Cassiopeia. He showed that these changes were conditioned by changes in the power of ejection of substance from the star, with which the glow of the envelope changed. The use of data of observations permitted determining how characteristics of the envelope

changed and constructing the theoretical light curve of a star. An explanation of changes of profiles and intensities of bright lines in the spectrum of γ Cassiopeia were given also (V. G. Gorbatskiy, 1951). With the help of the same theory Tsoy Dyay O (1956) determined parameters of envelopes for Be-type stars, which belong to different subclasses, and, proceeding from this found that Be-type stars in one year eject an amount of substance of the order of 10^{-7} to 10^{-8} mass of the sun.

On the basis of the theory of moving envelopes of stars the spectra of WR stars were investigated. For them S. G. Slyusarev (1955) calculated the intensity of bright lines of hydrogen and ionized helium and, proceeding from this, found the relative amount of these elements in their envelopes. S. V. Rublev calculated the profiles of the spectral lines for WR stars (1960, 1963).

Among the theoretical works on astrophysics in the USSR a conspicuous place is occupied by the investigations of novae. V. A. Ambartsumyan was based on the assumption about the fact that at the very beginning of an outburst of nova from the star the envelope will be separated, expanding at high speed. For this model of a flare the theoretical light curve of a star was built and the relationship between brightness of star and mass of discarded envelope (V. A. Ambartsumyan, 1939; Sh. G. Gordeladze, 1937). E. R. Mustel' treated outbursts of nova from somewhat different positions (1949), assuming that the envelope is discarded at the time of maximum brightness, but before this there occurs a swelling of the star. Mustel' attributed a large part in this phenomen of nova outburst to magnetic forces (1956). At present the first of these points of view is more completely developed theoretically.

Transfer of radiation through the expanded envelope of the nova prior to the moment of maximum brightness was examined by V. V. Sobolev (1954), who determined the change of brightness and temperature of the envelope in time. It was assumed that the glow of the envelope in the initial period of the outburst occurs due to both the energy inside it and the energy of the star.

One of the sources of the glow of novae can be the kinetic energy of the substance ejected by the star after breakdown of the envelope. Mustel' (1948) first indicated the possible value of this factor for the appearance of the bright bands in the spectrum of nova. The influence of ejection of substance on brightness of a star and dynamic action of the flow of substance on the envelope was investigated by V. G. Gorbatskiy (1960, 1962), who showed, in particular that the internal layers of an envelope under the impact of the flow are heated to a temperature of several hundred thousand degrees. Heterogeneity in the directions of the powerful corpuscular stream with an overall mass of the order of the mass of the envelope can lead to a rupture of the envelope into separate gas clusters, which, as observations show, makes up the envelope in the period after maximum.

Certain works examined possible causes of ejection of substance from stars. One such cause was assumed to be light pressure. Even in 1934 B. P. Gerasimovich at Pulkovo tried to explain variable ejection of substance from Be-type stars by the action of radiation pressure (B. P. Gerasimovich, 1934). The forces of radiation pressure on light atoms (C, N, O, S) were calculated by S. B. Pikel'ner (1947). S. V. Rublev (1959) offered a criterion for determining when an outflow of substance from giant stars is possible. The magnitude of light pressure in the atmospheres of stars was estimated by I. N. Minin (1963), who found that it can cause the observed accelerated motion of atoms in the envelope of these stars.

Another cause of the ejection of substance can be explosion in mineral resources of the star. Strong explosion should lead to the formation of a shock wave. The speed of the shock wave increases as it approaches the surface of the star. Under the impact of the wave the external layers of the star can detach and fly into space at high speed. Propagation of shock waves in stars with subsequent breakdown of the envelope was examined by L. E. Gurevich and A. I. Lebedinskiy (1955), who assumed that explosion occurs in peripheral regions of the star, and also by L. I. Sedov (1956) for the case of central explosion. Propagation of a shock wave considering interaction

of it with radiation and the possibility of separation of the envelope of a red giant under the impact of the wave were investigated by S. A. Kaplan and I. A. Klimishin (1959). The possibility of stationary supersonic outflow from the stellar atmospheres (I. A. Klimishin, 1962) was discussed also. The magnitude of mass loss upon breakaway of the envelope depending upon energy of explosion was calculated in a joint work by D. K. Nadezhin and D. A. Frank-Kamenetskiy (1962).

The theory of explosions and propagation of shock waves in stars is still far from completion, but results obtained in both these works and by many foreign theoreticians are of great interest for the explanation of stellar outbursts.

We can mention certain other investigations in the same general areas. Thus, I. S. Shklovskiy (1960), using data about radio emission from nebulae – envelopes of stellar supernovae – found that supernovae of type II prior to outburst were very massive stars and that the outburst in them should be analogous to the outburst of the usual nova. S. A. Kaplan (1962) examined conditions with which the acoustic wave appearing during explosion in mineral resources of a star is turned into a shock wave. The mechanism of the rapid transfer of energy liberated in the mineral resources of a star after a weak explosion into the external layers of the star without a shock wave was proposed by V. G. Gorbatskiy (1964). V. S. Imshennik and D. K. Nadezhin (1964) jointly studied the outburst of supernovae of type II from the gas-dynamic point of view. Furthermore, certain problems about the motion of gas in nonstationary stars were discussed earlier by K. I. Stanyukovich (1955).

Expansion of the nova envelope leads to rapid decrease of density in the envelope and transition to the "nebular stage," when according to the character of the outburst it is similar to nebula. Changes in the power of ejection of substance from a star, occurring during nebular stage cause noticeable disturbances of the radiant equilibrium in the envelope. Study of the corresponding phenomena caused the necessity of development of a theory of nonstationary

field of radiation, which so far is being developed chiefly in our country. These problems were first systematically examined by V. V. Sobolev (1952). He also applied his own theoretical conclusions to the study of a series of cases of the absence of radiation equilibrium in nova envelopes. Still earlier he examined one particular problem of the theory of a nonstationary field of radiation — change of ionization in a stellar envelope under the effect of rapidly increasing radiation. On this basis the mass of the envelope of Nova Herculis 1934 was determined (V. V. Sobolev, 1950). For this star I. N. Minin (1952) solved the problem of the change of electron temperature of the envelope in the absence of radiation equilibrium in it. A disturbance of radiation equilibrium also occurred during secondary outbursts of the star Nova Herculis 1950. The influence of these outbursts on the spectrum was studied by V. G. Gorbatskiy (1961). He investigated also the nonstationary quality of the radiation field in the envelope of Pleione (much observed Be-type star in the pleiades) and found (1954) that the appearance of narrow absorption lines in its spectrum is caused by the growth of intensity of stellar radiation in the distant ultraviolet region of the spectrum.

Glow in the absence of radiation equilibrium must frequently be encountered when the action of a shock wave on gas is studied. Gas heated by the wave luminesces, and consequently is not in a state of radiation equilibrium. Problems connected with luminiscence of gas in interstellar conditions were studied by Kaplan and Pikel'ner. Their work is mentioned in the section "Interstellar Medium and Planetary Nebula." The luminiscence of the atmosphere of a long-period variable after passage of a shock wave was studied by V. G. Gorbatskiy (1961), who on this basis gave an explanation of the bright-line spectrum of such stars. R. S. Iroshnikov (1961) solved the problem of propagation of a shock wave through the atmosphere of RR Lyrae stars and determined the spectrum changes caused by the wave.

During the investigation of shock wave action on gas, besides questions connected with luminiscence of the medium the problem

arises of radiation transfer in the medium with a moving boundary. Such a problem occupied S. A. Kaplan, I. A. Klimishin and V. I. Sivers (1960), who composed equations for the probability of a yield of quantum, absorbed on certain depth, from a medium and solving them for a number of cases.

The theory of nonstationary diffusion of radiation was considerably developed by I. N. Minin (1962, 1964), who proposed a new method for solving different problems. The basis for this method is the fact which he established that the laplace transform from any function characterizing the dependence of the radiation field on time may be obtained from the solution of the corresponding stationary problem.

When the density of substance in the envelope is low and the radiation density also is small, in the spectrum appear bright forbidden lines. The important problem of accumulation of atoms in metastable states, during transitions from which appear forbidden lines, was examined by V. A. Ambartsumyan even in 1933. He determined, in particular, the conditions for which forbidden lines become comparable in intensity with permitted lines. By forbidden lines in the spectra of novae and long-period stellar variables certain physical properties of envelopes were determined (M. A. Vashakidze, 1938; V. G. Gorbatskiy, 1961).

Emission spectra of nonstationary stars contain besides lines of hydrogen and helium and forbidden lines many permitted lines of complex atoms, in particular N III. A. A. Nikitin (1963) determined atomic characteristics of N III and with their help analyzed corresponding observations for novae and Wolf-Rayet-type stars.

The number of problems whose theoretical development has just begun but whose solution may possibly essentially expand ideas about stellar outbursts include studies of stellar outbursts for types T Tauri, UV Ceti and certain others. The extraordinarily rapid increase of stellar brightness, connected mainly with strongly increased radiation in the continuous spectrum, cannot be caused

by simple heating of the surface of the star. In the opinion of V. A. Ambartsumyan (1954), continuous emission appears as a result of the ejection from internal layers of a star of a certain portion of intrastellar substance which is the source of energy. From this point of view at Byurakan many authors examined outbursts of a series of stars.

For understanding the nature of flare stars the work of D. A. Frank-Kamenetskiy (1963) is of essential values it showed that when superthermal electrons are in the radiating gas, the spectrum should possess certain peculiarities characteristic for the spectra of flare stars. Investigations in this direction were carried out by I. G. Kolesnik (1965).

Problems in the theory of envelopes of nonstationary stars are examined in the monograph of V. G. Gorbatskiy and I. N. Minin "Nonstationary Stars" (1963).

Internal Structure and Stellar Evolution

Determination of the internal structure of a star requires knowledge of the sources of energy determining its luminosity, and the optical properties of the internal substance, since in the transfer of energy in a star the most important role belongs to radiant thermal conduction. Before solving these problems, studies of the internal structure of stars led chiefly to mathematical analysis of equilibrium equations for gas spheres. Certain general conclusions were obtained with respect to the properties of gas configurations which made it possible to estimate temperature and pressure in a star — A. Eddington (1926), S. Chandrasekar (1939). A number of questions connected with clarification of stability of gas spheres was examined by A. B. Severny (1941, 1948). In particular, he investigated in detail the possibility of convection in stars and showed that when sources of energy are chiefly in the central regions of a star, in its nucleus energy transfer is carried out basically by convection.

In 1939 G. Bete established that thermonuclear reactions of

the carbon cycle under conditions existing in stars must be carried out and can ensure the observed yield of energy. Approximately at the same time detailed calculations of the coefficient of opacity of stellar substance were carried out in a very wide range of temperatures and pressures and for different chemical composition of gas. From this time calculations of models of stars of different classes were made, giving the distribution of temperature and density in the star along the radius.

Many calculations have been made for the red giants. If a star is built according to a simple model (homogeneous), i.e., inside it there is no surface on which properties of substance are changed by a jump, then the central temperature is inversely proportional to the radius of the star. For the red giants radii are very great, and their central temperature is so low that it cannot ensure a flow of nuclear reactions. To explain the glow of a red giant it is necessary to use a more complex model and to consider that the star consists of an isothermal core and envelope of low density. Energy release occurs near the boundary of the nucleus. Soviet astrophysicists calculated a significant number of models of red giants (A. G. Masevich, 1948; Ye. I. Sushkin, A. O. Reznikov). A. G. Masevich examined also the structure of the class B hot giant, red dwarf and subdwarfs. D. A. Frank-Kamenetskiy (1955) studied models of stars of the sun's type under the condition of energy release by proton-proton reaction (hydrogen-helium model, neglecting heavy elements), which, as was clarified in the 1950's, in these cases is more likely a source of energy than a carbon cycle reaction. Models with coefficient of absorption inversely proportional to the square of temperature were calculated also (T. A. Emin-zade 1953, 1954).

The validity of conclusions of the theory of the internal structure of stars can be checked by comparison of the mass-luminsotiy dependence obtained from theory with the observed dependence. Parenago and Masevich (1950) investigated in detail the form of this dependence for different sequences of stars on the Hertzsprung-Russell diagram.

Kozyrev (1950) offered a stellar model consisting of hydrogen, where the opacity in it was considered to be caused only by the scattering of radiation on free electrons. However, calculable central temperature of the star in this case turns out to be so low that energy release by nuclear eactions cannot occur, and therefore the question of energy sources or stellar flow remains unsolved. The established large amount of helium in stars does not agree with the assumptions used to calculate Kozyrev's stellar model. At the same time, as D. A. Frank-Kamenetskiy showed (1959), during calculation of hydrogen absorption in the center of a purely hydrogen star the temperature must be sufficient for proton-proton reactions.

A special class of stars with respect to internal structure are the white dwarfs, consisting of degenerate gas. In the mineral resources of these stars there need not be a noticeable quantity of hydrogen, since otherwise in them nuclear reactions would be very intense (thanks to the great density of substance) and they would have a high degree of luminosity. As a possible method of energy release for white dwarfs S. A. Kaplan (1949) took gravitational compression and estimated the cooling time of the star.

In the 1930's in astrophysics the properties of degenerated gas were actively studied. In our country the beginning of such study was the work of L. D. Landau (1932), who first examined the structure and stability of configurations consisting of relativistic degenerate gas and obtained the value of critical mass for such a configuration. In postwar years S. A. Kaplan (1949) turned to these problems, calculating the central density of the configuration consisting of relativistic degenerate electron gas and nonrelativistic nuclear gas, found in Einstein's gravitational field. It turned out to be insufficient for the appearance of a neutron nucleus.

The structure of the configuration with densities of the order of nuclear density was thoroughly studied by V. A. Ambartsumyan and G. S. Saakyan (1960, 1961). Upon a growth of density in gas different hyperons must consecutively appear, rendered stable in accordance with Pauli's principle. The concentrations of different

hyperons depending upon density were calculated. On this basis the equation of state of substance for densities of the order of nuclear and greater is examined, a model of the baryon star is built and the maximum masses (around one solar mass) and radius (around 10 km) are found. G. S. Saakyan (1962) with the help of the nonrelativistic theory furthermore calculated mass and radius of hypothetical neutron configurations.

Work on study of the structure of superdense configurations is closely connected to studies of stellar associations at the Byurakan Observatory. The name stellar association was applied to stellar systems discovered and studied by Ambartsumyan jointly with B. Ye. Markaryan (1949), and which apparently are very young formations — their age, according to the estimates of these authors, is several million years. According to the views of V. A. Ambartsumyan (1957), stars making up an association recently came from certain hypothetical "protostars," for which it is possible to assume that they are very dense bodies. This point of view on the origin of stars and the widespread opinion about the origin of stars from diffuse substance are studied in greater detail in the section "Stellar Cosmogony."

In studies of the internal structure of nonstationary stars in the USSR the theory of stellar pulsations has had considerable development, the beginning of which was the work of A. Eddington (1918). S. A. Zhevakin (1953) advanced and developed in detail the theory of natural oscillations of cepheids, according to which the excitation of pulsations is peripheral and is caused by a drop of the adiabatic index in the zone of double helium ionization. S. A. Zhevakin on the basis of his own theory explained the observable phase shift on the light change curve relative to the curve of radial velocities (1957) and interpreted of the period-luminosity dependence (1958), which was not possible with the old theory. At the same time another view on pulsation was discussed, according to which the zone of biggest pulsation amplitude is occupied by the central stellar regions and coincides with the zone of energy liberation (D. A. Frank-Kamenetskiy, 1955). Further development of

the theory of pulsations in the works of both Soviet and foreign scientists indicates that Zhevakin's theory of natural oscillations of the cepheids is nearer to reality than the theory of central pulsations.

The problem of nonstationary transfer of radiation inside a star, examined by V. V. Sobolev (1960), is of essential value for the theory of internal structure of nonstationary stars. In processes determining the nonstationaryness in magnetic stars, the connection of the magnetic field of a star with motions in it, expressed in deformation of the magnetic field and trapping of the magnetic lines of force (discussed by A. J. Kipper (1955) can play a role. Another important factor affecting the internal structure of both ordinary and nonstationary stars is stellar rotation. A work of V. V. Porfir'yev (1962) studies the rotation of polytropic stars and circulation in stars connected with rotation. The influence of stellar rotation on evolution was discussed by V. A. Krat (1948).

Studies of the internal structure of stars are connected with marks on nuclear reactions in stars, leading to the appearance of new elements, including the appearance of a mixture of substance and antimatter (epiplasma) during outbursts of supernovae (D. A. Frank-Kamenetskiy, 1962), gravitational collapse (Ya. B. Zel'dovich), the role of neutron radiation (B. M. Pontekorvo, A. G. Masevich and others). Some of these problems along with other questions related to the structure of stars and phenomena in them are examined in a monograph of D. A. Frank-Kamenetskiy "Physical Processes Inside Stars" (1959).

One area of study in the USSR on stellar development was investigation of stellar evolution caused by loss of mass. A. G. Masevich (1949) and V. G. Fesenkov (1952) gave evolutionary meaning to the main sequence on the spectrum-luminosity diagram considering that evolution is caused by both transformation of hydrogen into helium and continuous loss of mass from the stellar surface. It was assumed that the rate of mass decrease is proportional to stellar luminosity, but the physical processes leading to the assumed

mass loss were not examined. The absence of distinct ideas about possible mechanisms of mass loss in this theory essentially hampers its development.

B. A. Vorontsov-Vel'yaminov (1947) proposed a diagram of the evolution of nonstationary stars, accompanied by mass loss along the so-called white-blue sequence. The sequence goes from stars of class O through WR stars and novae to blue dwarfs. Massive hot stars, ejecting substance at first by continuous outflow, but then by discarding the envelopes, gradually obtain a degenerate nucleus and turn into white dwarfs.

It was not possible to speak briefly of all works on stellar physics conducted in the USSR, and it was necessary to stop only on the most promising directions. Fast growth of the number of investigations and continuing increase in level create confidence that the leading place occupied in the postwar period by Soviet researchers in solving many problems of stellar physics in the next few years will be strengthened still more.

INTERSTELLAR MATTER AND PLANETARY NEBULAE

The study of interstellar matter - diffuse substance filling the space of our and other stellar systems - is one of the youngest areas in astrophysics. Actually the middle of this century completed only the period of "initial accumulation" of factual material and completed the formation of basic concepts. At the same time the role played by the study of interstellar medium in the common progress of astrophysics is extraordinarily great, just as also the contemporary value of these studies for all astronomical science.

The study of interstellar medium promoted augmentation of both the experimental and theoretical arsenal of astrophysics. The extreme difficulty in obtaining actual data demanded an increase of the power of astronomical tools and led to the creation of specialized instruments which were new in principle, such as, for example, nebular spectrographs. Later study of the interstellar medium promoted the introduction of radio electronics to observation astrophysics. Investigations of faint nebulae brought to life the methodology of photographing the sky through narrow-band light filters; in recent years this problem has stimulated the development of methods of interference spectroscopy in reference to the observation of weak extended objects.

Development of the physical theory of diffuse matter was an important contribution to theoretical astrophysics. Many divisions

of this science, now considered classical – like the theory of the hydrogen spectrum or the mechanism of excitation of forbidden lines – were developed initially for the needs of the physics of gaseous nebulae. In the last two decades the physics of interstellar medium introduced to theoretical astrophysics methods of gas dynamics and magnetohydrodynamics, and also the physics of high-energy particles.

The problem of interstellar medium serves a connecting link between all main divisions of astrophysics and stellar astronomy. Actually, by contemporary opinions stars are born from diffuse matter and constantly interact with it, changing mass, chemical composition, state of ionization, dynamics. Certain nonstationary stars actually surround themselves by rarefied gaseous envelopes. In turn our stellar system, as also other galaxies, contains involved complexes of interstellar matter, remaining in constant motion and change and giving a beginning to a new generation of stars. It is possible that extremely rarefied matter also fills intergalactic space. Finally, the problem of interstellar medium is intimately connected with the fundamental problem of sources of space radio emission. Everything said permits estimating the general cosmogonic and cosmologic role of interstellar medium.

At present by interstellar medium it is accepted to understand the totality of rarefied gas (chiefly hydrogen), solid dust particles, cosmic rays and magnetic fields connected with the gas. Gas and dust fill the whole volume of our stellar system. Their average density is extraordinarily small (less than $1 \cdot 10^{-24}$ g/cm^3), but local density can be considerably larger. It is accepted to consider that the space distribution of gas and dust has a clearly expressed cloudy structure, where density in clouds exceeds density in intercloud space 10 times and more. When clouds are located next to bright stars, they are observed in the form of light and dark gas-dust nebulae. However, the basic mass of dark interstellar matter is not seen directly and can be investigated by only indirect methods, for example by the absorption of radiation of remote stars. The presence of cosmic rays and magnetic fields

connected with interstellar gas also appears only indirectly — in nonthermal radio emission, gas-dynamic effects and polarization of radiation.

Similar ideas were formed during the period of the decades of tedious collection of facts, theoretical and laboratory investigations. At the beginning of the XXth Century not only were there no concepts of the quasi-continuous gas-dust medium, but even the very presence of dispersed interstellar dust and gas was considered very doubtful. Proofs of their existence appeared only in the second and third decade of this century; the same thing is true also of the development of basic theoretical propositions of the physics of interstellar matter.

At the beginning of the XXth Century the study of interstellar matter proceeded in three practically independent directions. First, the oldest and probably the most difficult direction was the investigation of general space absorption of light and the accompanying phenomena. As it is known, the founded assumption of the existence of light absorption in interstellar space was first expressed by the famous Pulkovo astronomer V. Ya. Struve in 1847. In the second half of the XIXth and beginning of the XXth Centuries many researchers tried to give a final proof to the existence of interstellar absorption, to determine its character and to measure the magnitude. Their number in particular includes G. A. Tikhov and V. G. Fesenkov. The solution to the problem, as already was mentioned, turned out to be possible only in the 1930's after the development of fine statistical methods of stellar astronomy. Since then the study of interstellar absorption of light has been an essential division of stellar astronomy. In our country much work in this area (see the section "Structure of the Galaxy") has been done and still continues.

The second direction, which later rendered a huge influence on development of the theoretical apparatus of the physics of interstellar matter and theoretical astrophysics as a whole, was the study of planetary nebulae. These are gaseous envelopes surrounding nonstationary stars of defined type, and probably being formed due to the ejection of substance from the material star-nucleus of the

nebula. Planetary nebulae in general are considerably denser and more compact than typical gaseous nebulae, and consequently possess a greater surface brightness and are more accessible to observation. Together with that physical conditions in planetary nebulae are also characteristic for ionized interstellar gas — one of the basic forms of existence of interstellar matter. Furthermore, in planetary nebulae the interaction of gas with a star exciting its glow carries a comparatively simple character. The above explains just why planetary nebula turned out to be the "touchstone" for the physics of interstellar matter.

Thanks to the comparative brightness of planetary nebulae and their unique appearance they have long attracted the attention of observers. By the 1920's astrophysicists had already sufficient material requiring theoretical interpretation. A pioneer of these investigations in our country was one of the first and greatest of Soviet astrophysicists — B. P. Gerasimovich,[1] who at first worked in the observatory of Kharkov University, and then from 1929 as the director of the Pulkovo Observatory, which he directed until his tragic death in 1937.

The first work of B. P. Gerasimovich, dedicated to planetary nebulae, appeared in 1922. Starting his investigations, he intended to study the causes of specific space forms inherent to these objects. In the 1920's dynamic and evolutionary ideas still had not penetrated astrophysics. Therefore, in agreement with the ruling conceptions at that time Gerasimovich (see Gerasimovič, B., 1925) tried to examine forms of planetary nebulae as equilibrium configurations of gas matter under the impact of the forces of attraction of a central star and repulsive forces of light pressure.

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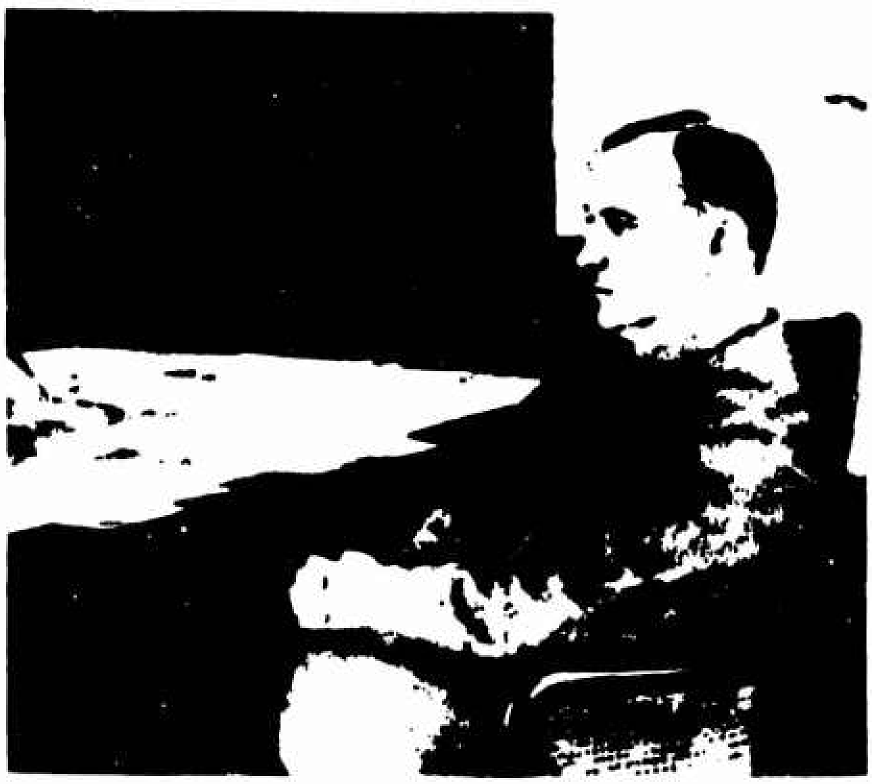
[1]Boris Petrovich Gerasimovich was born in 1889 in Poltava. He prepared at Kharkov University under L. O. Struve, then passed his probation at Pulkovo for A. A. Belopol'skiy, after which he taught at Kharkov University. From 1927-1929 he was on a scientific mission to the United States, and soon after his return was named director of the Main Astronomical Observatory of the Academy of Sciences USSR at Pulkovo. He was a member of the Astronomical Council at the Academy of Sciences USSR from its establishment.

In the course of this investigation Gerasimovich (1925, 1927a) met with the necessity of a more precise determination of a number of physical parameters of the nebulae. He studied the state of substance in planetary nebula and its ionization. Combining astrophysical and stellar-astronomical methods, he determined the absolute luminosity of nuclei and definitized their basic characteristics (1927b, 1929, 1931). To Gerasimovich in particular belongs the conclusion that the nucleus of planetary nebulae is a star of small mass. Now we see that certain works of Gerasimovich were somewhat premature in the sense that the complexity of the problem at hand frequently exceeded the possibilities of the still unestablished theory. Many of his thoughts and results still retain their value.

At the beginning of the 1930's, after Bowen's identification of the primary spectral lines of planetary nebulae and Zanstra's development of the principles in the theory of glow of these objects, interest toward it considerably increased. In the light of new theory the question about light pressure, traditional for the physics of planetary nebulae, found a new direction. It became clear that the basic role here should belong to the field of resonance radiation in the L_α hydrogen line. Investigations of this effect were begun at Pulkovo by V. A. Ambartsumyan (see Ambarzumian V., 1932, 1933), who solved the problem about determination of the fields of L_c- and L_α-radiation of hydrogen and about light pressure in planetary nebula expanding with constant speed during coherent scattering. From these works it followed that light pressure is the paramount factor causing expansion of planetary nebulae. At the same time Ambartsumyan developed a simple method of determining temperatures of nuclei by the relation of intensities of lines of ionized helium and hydrogen in the spectrum of nebula, and, investigating the mechanism of glow of planetary nebulae, definitized the conditions of appearance of forbidden lines. He first proposed one of the methods of estimating electron temperature of gaseous nebulae by the relationship of intensities of nebular and auroral lines of the O ion III (1939).

From the end of the 1930's studies of planetary nebulae by methods of transport theory of radiation were continued at Leningrad University by V. V. Sobolev. One of the essential results of this work was a conclusion concerning catastrophic decrease of light pressure when a velocity gradient appears in the nebula. V. V. Sobolev also developed a method of determining the electron temperature of a nebula through the power balance of the electron gas taking into account collisions. Besides planetary nebulae he investigated also gaseous envelopes of nonstationary stars; results of all these works are summarized in his monograph "Moving Stellar Envelopes" (1947).



Boris Petrovich
Gerasimovich

1889-1937

In subsequent years V. V. Sobolev and his group obtained valuable results in the theory of incoherent scattering of radiation in gaseous nebulae (V. V. Sobolev, 1955-1957; V. V. Ivanov, 1962). Among them one should note the resolution of the problem about light pressure in the case of incoherent scattering, which along with results of Zanstra, Koelbloed and Miyamoto in general put under doubt the significance of light pressure for dynamics of planetary nebulae.

At the beginning of the 1930's a study of planetary nebulae was begun at Moscow by B. A. Vorontsov-Vel'yaminov. He is responsible for a large number of very valuable and various works, among which be noted an original semi-empirical method of determining distances to planetary nebulae (see Vorontsov-Veljaminov B., 1933), an original method of determining temperatures of nebular nuclei (1931), work on spectral classification of nuclei and classification of visible forms of planetary nebulae. He also published several catalogs of planetary nebulae obtaining wide international fame, the last of which contains around 600 objects (1962). Vorontsov-Vel'yaminov also made the first attempts to investigate the space structure of planetary nebulae according to the visible distribution of brightness (1948). Recently Vorontsov-Vel'yaminov and his group undertook an extensive spectrophotometric investigation of planetary nebulae for the purpose of mass determination of their physical parameters (1964, 1965). It is necessary to note the 1948 second publication of Vorontsov-Vel'yaminov's book "Gaseous Nebulae and Novae," which for a long time was the only and also very complete aid in the physics of gaseous nebulae.

Of the work on planetary nebulae carried out in the USSR one should note the small but important investigation of I. S. Shklovskiy, published in 1956. In it the bases of the general evolutionary theory of planetary nebulae are laid, making it possible to study the cosmogonic role of these objects. I. S. Shklovskiy first indicated stars of the red giants type of moderate mass as possible precursors of planetary nebulae and their nuclei. At present the theory of I. S. Shklovskiy and the original method of determining distances to planetary nebulae based on it have been confirmed by observations and have universal acknowledgement. These investigations are continued in works G. S. Khromov. In recent years Shklovskiy's group carried out systematic measurements of radio emission of planetary nebulae (G. S. Khromov and others, 1965).

It is necessary to stop also on works of G. A. Gurzadyan, who in the 1950's began the first study of the dynamics of planetary nebulae. Basic results of the numerous works of G. A. Gurzadyan are included by them in the generalizing monograph "Planetary

Nebula" (1962). Although these works have a defined value, they did not obtain general acknowledgement.

It is difficult to enumerate here all Soviet researchers who have made some contribution to the traditional subject for our astronomy – the study of planetary nebulae. It is necessary to note the work of P. P. Parenago (1946), who more precisely determined the scale of distances and studied the space distribution of planetary nebulae, V. I. Pronik (1957) on the theory of power balance of electron gas in planetary nebulae, observation work of L. P. Metik and R. Ye. Gershberg (1964), and also N. A. Razmadze (1958).

The work of A. Ya. Kipper, having important consequences both for the physics of planetary nebulae and interstellar matter in general, deserves separate mention. He explained the seeming excess intensity of the continuous spectrum of gaseous nebulae by the mechanism of two-photon radiation of hydrogen (1950), which he discovered in 1950.

As is easy to see from the preceding section, theoretical work predominated in study of planetary nebulae in the USSR. This was the result of the insufficient instrument (degree of) equipment of our astrophysicists. In still greater degree this circumstance was reflected on the development of the third traditional direction in the study of interstellar matter – investigation of interstellar gas, dispersed in space between dense gas clouds. This component of interstellar material can appear only in the form of weak lines and absorption bands in the spectra of certain remote stars. In our country there were practically no similar investigations, requiring the most powerful instruments possible, and we can mention only individual episodical works in this area (for example, the joint work of Gerasimovich and Struve or the several works of O. A. Mel'nikov). As if to counterbalance this circumstance, Soviet astronomy has preeminence in the development of another, comparatively young and very important area of the physics of interstellar matter. This direction – investigation of light gaseous nebulae – is connected

with the name of Grigoriy Abramovich Shayn.[1]

Luminescent dense thickenings of interstellar matter, called diffuse gaseous nebulae, have been long known. In view of the complexity and variety of their observed forms, which extraordinarily confuses the problem of classification, and also due to the weakness of glow these objects are very difficult to study. Only in 1922 did E. Hubble discover the existence of a connection between light nebulae and hot stars, which permitted comprehending the cause, and later the mechanism of the glow of these nebulae (as was mentioned above, for diffuse and planetary nebulae it is practically identical). After that extremely important discovery interest toward the study of diffuse nebulae dropped off, possibly in view of the absence of new fruitful ideas. The following stage in development of this branch of astrophysics was opened at the end of the 1940's by the works of G. A. Shayn, a great part of which was in collaboration with V. F. Gaze.

In 1948 at Simeiz Shayn began photography of gaseous nebulae on a fast lens camera. Observations were conducted using his original method, which made it possible to obtain photographs of nebulae in narrow spectral bands, including basic emission lines of their spectra.

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[1]Shayn, Grigoriy Abramovich was born in 1892 in Odessa, finished the Yur'yevskiy (now Tartuskiy) University, from 1924 to the end of his life (1956) worked in the Crimea – at Simeiz, and after the war – at settlement Nauchnyy. G. A. Shayn is one of the creators of the new astrophysical observatory of the Academy of Sciences USSR (KrAO), where there is now a 2.6-meter reflector of his name.

The basic region of his activity was study of the physical nature and development of stars and light diffuse nebulae. Together with O. L. Struve (United States) he detected the axial rotation of the stars; he discovered the anomalous large relative amount of the heavy carbon isotope (C^{13}) in the atmospheres of the so-called carbonic stars. Prolonged (jointly with V. F. Gaze) investigation of diffuse nebulae in our and other galaxies led him to important conclusions concerning the character of motion of substance in such nebulae, the role of magnetic forces in galaxies, and the place and role of diffuse matter in the cosmogonic process. Shayn was an active member of the Academy of Sciences USSR (from 1939) and honorary member of many foreign academies and societies.

Similar procedure increases the contrast and thus allows observation of weaker extended objects. Numerous unique photographs of gaseous nebulae served as the basis for the 1952 "Atlas of Diffuse Gaseous Nebulae" by G. A. Shayn and V. F. Gaze. On the basis of observation material obtained then and in subsequent years Shayn constructed the evolutionary theory of diffuse nebulae. Starting from the investigation of their structure, he discovered the fact that nebulae expand, which leads finally to their disintegration. This process explains the effect of bunching in the space distribution of diffuse nebulae. Further, investigating the connection of nebulae with the O- and B-stars exciting their glow, Shayn constructed an evolutionary diagram according to which nebulae lose their initial connection with hot stars as they expand and finally can become invisible. The cosmogonic role of diffuse nebulae was investigated, and an important conclusion made concerning the joint appearance of groups of hot stars and diffuse nebulae.

Another fundamental cycle in the work of Shayn was investigation of the galactic magnetic field. The first indications of its existence were given by the discovery of interstellar polarization of light, interpreted as the result of scattering on dust particles oriented by magnetic field (see below). G. A. Shayn offered a new promising method of studying the galactic magnetic field by space distribution and forms of gaseous nebulae. As a result of this work it was possible to compose an idea about distribution of magnetic fields in the Galaxy, to prove their connection with spiral branches and even to study local heterogeneities of the field. It is possible to affirm that the work of Shayn was the foundation for subsequent development of ideas about the interaction of gas and magnetic field in the Galaxy.

Besides the two basic cycles of work for the study of interstellar matter published in the period from 1952-1956, G. A. Shayn completed at the same time, several other studies of nebulae. Jointly with S. B. Pikel'ner he studied turbulence in the Orion nebula and tried to determine the presence of dust in certain gaseous nebulae; together with I. S. Shklovskiy he identified galactic sources of

radio emission. Within the bounds of this article there is no possiblitiy to stop on the work of G. A. Shayn in greater detail; it is difficult even to give any consistent bibliography of his numerous transactions. Concerning intensity (with which he worked) we can say that in a period of around five years Shayn published over 60 works (part of them in co-authorship with V. F. Gaze and S. B. Pikel'ner), dedicated to the investigation of nebulae. Therefore we refer interested readers to the detailed scientific biography of Shayn written by S. B. Pikel'ner (1957) and containing also a full bibliography of his publications.

For his work G. A. Shayn obtained international acknowledgement and fame. In the Soviet Union he founded a new direction – investigation of diffuse gaseous nebulae and gas components of the interstellar medium. In recent years these investigations were expanded both in observations and theory. It is necessary to mention work of P. V. Shcheglov and V. F. Yesipov on improvement of the method of observations of faint nebulae (P. V. Shcheglov, 1963), and also various observation and theoretical work of S. B. Pikel'ner, R. Ye. Gershberg, E. A. Dibaya, R. N. Ikhsanov, V. I. Pronik and many others carried out during the period of the last 10 years (see S. A. Kaplan, S. B. Pikel'ner, 1963). The work of G. A. Shayn on the structure of diffuse nebulae and the magnetic field in them served as a push to development in the Soviet Union of research in space gas dynamic and magnetohydrodynamics. In this region in recent years S. A. Kaplan and S. B. Pikel'ner worked especially actively. S. A. Kaplan carried out numerous works on turbulence, shock and ionization fronts in interstellar gas and nebular (1958). The primary area of concern in the work of S. B. Pikel'ner is investigation of the interaction of gas and magnetic fields and cosmic rays in the Galaxy. A considerable event was the excellent book of S. A. Kaplan and S. B. Pikel'ner "Interstellar Matter" (1963) – the first generalizing monograph on this subject in the world of astrophysical literature. The book contains also the basic results of the work of the authors and other Soviet astronomers studying interstellar matter and nebulae.

Grigoriy Abramovich
Shayn

1892-1956

As was mentioned earlier, one of the components of interstellar matter is space dust. Its study is very important since it is the basic agent responsible for interstellar absorption of light. Furthermore, space dust, being a component part of interstellar matter and gaseous nebulae, should be genetically connected with gas. The nature of this connection is still not fully clear, and, in turn, presents an interesting problem. The study of space dust is hampered by the faintness of the light dispersed by the dust as compared to the glow of the gas component. In certain cases, however, so-called reflective nebulae are observed, where due to defined causes the glow of gas is comparatively faint and radiation dispersed by the dust predominates. These nebulae were first studied in our country at the end of the 1930's when V. A. Ambartsumyan and Sh. G. Gordeladze showed the existence of a statistical connection of these objects with the stars illuminating the dense dust clouds.

Study of the dust component of gas and reflective nebulae, in contrast to investigations of dark and rarefied dust, is conducted by methods close to the methods of studying light gas nebulae. Extensive investigations of reflective and gaseous nebulae (from the point of view of the amount of dust in the latter) were started around 1950 in the Astrophysical Institute AN Kazakh SSR by V. G. Fesenkov and D. A. Rozhkovskiy. Observations were conducted on a 50-centimeter telescope of Maksutov's system. Nebulae were photographed in red and blue rays, which permitted separating the gas and dust glow, since a considerable part of the energy of gas glow is concentrated in the red H_α line, while during scattering on dust particles the short-wave part of the spectrum is amplified. Results of these observations were issued in 1952 in the form of the "Atlas of Gas-Dust Nebulae."

V. G. Fesenkov and D. A. Rozhkovskiy observed a connection of young stars with dense spectral lines of nebulae. They constructed their own cosmogonic diagram of the appearance of stars in such spectral lines (V. G. Fesenkov, D. A. Rozhkovskiy, 1952a, b; V. G. Fesenkov, 1956). The diagram is based on the assumption that in dense gas-dust spectral lines profitable conditions are created for gravitational condensation of stars from diffuse matter.

An extensive investigation of reflective nebulae was in recent years carried out by D. A. Rozhkovskiy (1960, 1962, 1965). Study of these nebulae permits determining the scattering indicatrix and certain physical parameters of dust particles, which is of great value in theory. The transition from direct results of observations to the properties of particles as such is made by methods of the theory of scattering. In this region in the Soviet Union at various times so many various works have been carried out that their survey could be the subject of a special piece. Certain general information can be found in the monograph of V. V. Sobolev (1956). In recent years the theory of scattering in reference to interpretation of observations of reflective nebulae has occupied V. V. Sobolev (1960), I. N. Minin (1961, 1964), S. A. Kaplan (1952) and S. A. Kaplan and I. A. Klimishin (1953).

As was noted earlier, interstellar dust leads to polarization of the light of remote stars. According to existing opinions polarization appears during light scattering on equally oriented dust particles. Inasmuch as orientation of dust particles is due to the galactic magnetic field, polarimetric observations of remote stars give an indirect method of studying interstellar magnetic fields. Similar observations in our country have occupied V. A. Dombrovskiy (1950), who shared the preeminence of discovering this important effect with V. Hiltner and J. Hall. Polarimetric observations play an essential role and in the study of the dust component of diffuse and reflective nebulae. Numerous measurements of the polarization of radiation from similar objects were made in the 1950's by D. A. Rozhkovskiy at Alma Ata.

It is necessary to mention still one more class of objects — the so-called comet-shaped nebulae, which are being studied in the Soviet Union probably more effectively than anywhere else. These are weak and small nebulae, having the appearance of luminescent cones, at the vertices of which are not particularly hot stars; the spectrum of these formations indicates that besides gas they contain also dust. Investigations of comet-shaped nebulae were started by Ambartsumyan and Khachikyan (V. A. Ambartsumyan, 1955). At the present E. A. Dibay is also taking part. Ambartsumyan considers comet-shaped nebula to be the result of ejection of intrastellar matter from a just-formed nonstationary star. It is assumed that the actual star appears from nonstellar prestellar substance; the mechanism of ejection of the nebula is not indicated. Dibay (1960) interprets these objects as the result of compression of a dense gas-dust nebula as an ionization front created by radiation of a neighboring hot star passes through it. Flowing around the local heterogeneity of density, the ionization front additionally compresses it and promotes the appearance of a star, which later is observed in the vertex of the comet-shaped nebula.

In the number of components of interstellar material we mentioned also cosmic rays. By this is understood the totality of high-energy particles moving in interstellar space. Experimental study of cosmic

rays is the subject of a special division of physics. Indirect data about cosmic rays, their cosmogonic role and especially about their formation is supplied by radio astronomy. The physics of interstellar material also includes consideration of the influence of cosmic rays on the structure of the galactic magnetic field and on the interstellar gas connected with it. Existing ideas are still far from complete, and therefore it is difficult to put results in a sufficiently compressed form. In the Soviet Union I. S. Shklovskiy, S. B. Pikel'ner, S. A. Kaplan actively work in this region (see I. S. Shklovskiy, 1956; S. A. Kaplan, S. B. Pikel'ner, 1963). This division of the physics of interstellar material medium lies on a junction with radio astronomy, while the majority of investigations pertains exactly to the latter. Therefore we refer the reader interested in more complete information about the state of problem on cosmic rays to the seciton "Radio Astronomy."

STRUCTURE OF THE GALAXY

It is now common and ordinary to think that the sun and surrounding stars are in the Galaxy — a huge and extraordinarily complex system, counting not less than 10^{11} stars of various types, and a multitude of other objects — star clusters, dust and gaseous nebulae, etc.

Study of the Galaxy is not more than 200 years old. Little more than 100 years ago measurements of the distance to the nearest stars were begun. At the beginning of the XXth Century very little was known about the structure of the Galaxy. Separate elements of composition of the Galaxy had already been studied, but their role and place in the whole system remained vague. The analogies of our stellar system were not known then, since the idea that all the numerous nebulae observed in the sky are gas formations predominated. Only in 1924 E. Khabbl decomposed the separate parts of spiral nebulae into stars, and determination of the distances of these objects showed that they constitute huge stellar systems similar to our Galaxy.

The study of the Galaxy, to say nothing of its huge dimensions, is hampered by at least two things: the fact that the observer is inside the system, and the fact that interstellar space is filled by light-absorbing dust. Clarification of the last circumstance (1930) gave a huge push to the development of correct ideas about the structure of the Galaxy and essentially signified the approach of

the contemporary stage in the investigation of our stellar system. Thus, the fifty-year period of Soviet galactic astronomy in many respects coincides with the epoch of development of contemporary ideas on structure of the Galaxy in general. The study of galaxies occupies a conspicuous place in our science. For fifty years a multitude of works have been carried out dedicated to accumulation of material from observations, statistical comprehension, theoretical consideration of the Galaxy from the point of view of its dynamic properties. Study of the Galaxy and its separate elements is being developed in Moscow, Leningrad and Pulkovo, Abastumani, Byurakan and other centers of astronomical thought in the country. Besides the development of domestic instrument making, the equipment of our observatories with contemporary instruments has been beneficial. In several universities cadres are being trained in the specialty of stellar astronomy. Both Soviet and translated textbooks have appeared, in which the structure of the Galaxy is widely treated from totally different points of view.

In a short survey there is no possibility to present all works in the field of study of the Galaxy. We will mention only the most important areas of investigations.

In 1930 under the pressure of factual material it became undeniably clear that the space between stars is not empty, but is filled with a great amount of dust. Interstellar absorption of light leads to distortion of photometrical characteristics of remote objects and thereby hampers judgment of their true distances and, consequently, distribution in space. Soviet astronomers immediately comprehended all the importance of this question and joined work on its solution. In the 1930's a large cycle of works on large dust nebulae was carried out at Pulkovo. However, Wolf's method of stellar calculations which was used, as it turned out, could not give correct information about the extent of nebulae by line of sight. In 1938 K. F. Ogorodnikov developed his own method of studying dark nebulae and showed that they constitute comparatively small formations (3-15 ps), absorbing light from several tenths to several stellar magnitudes. In pre-war years Ambartsumyan completed a cycle of works which establishes a connection between dark nebuale and general

absorption in space. According to these investigations there is no necessity of introducing some uniform absorbing layer, and self-absorption is explained by discrete dark nebulae around 5 ps in diameter with absorptivity $0.2\text{-}0^{m}.3$. The present numerical data have been repeatedly definitized by Soviet and foreign authors, using different statistical methods (V. A. Ambartsumyan, B. Ye. Markaryan, T. A. Agekyan and others).

In the 1930's the idea that absorption of light is not especially great predominated. In 1940 P. P. Parenago (1906-1960) tried to study absorption based on general considerations that the absorbing matter has a gradient of distribution with respect to the galactic z-coordinate (perpendicular to galactic plane). The formula derived on this assumption permitted him to estimate the absorption per unit distance and indicated its dependence on galactic width. Absorption turned out to be essentially larger than was assumed earlier. In subsequent years Parenago definitized his theory, showing different absorption in various sections of the sky. Subsequently the parameters of Parenago's formula were again subjected to more precise definition, and the absorption distribution map became more detailed (A. S. Sharov, 1963).

The method of calculating the absorption of light developed by Parenago has been widely used in works dedicated to the structure of the Galaxy. Simultaneously with the search for general characteristics of absorbing matter extensive work is being conducted on the study of absorption in specific areas. A large photometric catalog of the colors of stars has been finished at the Abastumani Observatory by Ye. K. Kharadze. He and his colleagues are studying the absorption of light in a number of areas of the sky. In Georgia M. A. Vashakidze (1909-1956) investigated the absorption of light in extragalactic objects (1953). Absorption in near regions of the sun is being studied by V. B. Nikonov, who is using his own photoelectrical catalog of color indices of early stars.

In postwar years following an idea of G. A. Shayn the Crimean Astrophysical Observatory began detailed investigation of bands in

the Milky Way. In a number of regions of the sky photometry and spectral calssification of thousand stars was conducted. This material of observations was later used for detailed study of light absorption, and then space distribution of stars. It is true that the rather modest means of observations permitted penetration only to comparatively near regions of the sun (1-2 kps) (Ye. S. Brodskaya, L. P. Metik, I. I. Pronik and others).

In 1955 P. P. Parenago advanced a great plan for overall study of chosen areas in the Milky Way, which should give information both about the structure of the Galaxy and about the absorption of light. Astronomers of Kiev, Abastumani, Moscow began to follow this plan. Certain foreign observatories began work on separate stages of the investigation. The work in our country, in many respects promoted clarification of the role of interstellar dust during the study of the Galactic structure.

One of the most general characteristics of the Galaxy is number of stars in it. This question was examined by V. G. Fesenkov (1940) and T. A. Agekyan (1949). They based themselves on stellar calculations, carried out to the maximum weak stars. These investigations examined all stars without any separation into types. Parenago's approach was different. According to contemporary ideas our Galaxy consists of separate subsystems made up of stars with identical physical properties. Investigations conducted in our country clarified the characteristic of distribution of stars in the subsystems, and this made it possible to estimate the overall number of stars in the Galaxy. The difficulties of similar appraisals naturally are very great, inasmuch as in one way or another it is necessary to rely on knowledge of star density in the neighborhood of the sun and to extrapolate these data to the whole Galaxy. Apparently the total number of stars in the Galaxy is 10^{11}. Study of the distribution of stars by luminosity (functions of luminosity) and mass-luminosity dependence permits estimating the general mass of the stars of our stellar system. Other, dynamic methods of estimating the mass of the Galaxy and the obtained results will be described in the section "Dynamics of Stellar Systems." It turns out that other forms of

matter (gas and dust) compose only a small part of the mass of the Galaxy.

Another important integral characteristic of a stellar system, describing either all or a great part of it the integral color, which is determined by the whole stellar ensemble. Considerations about the color of the Galaxy in the direction of its pole were expressed by V. A. Ambartsumyan. Judging by color, our sun should be somewhere between spiral branches. Certain data about the structure of the Galaxy and its stellar composition can be gained by a study of the integrated spectrum of the Milky Way. Study of the spectrum of bright clouds in the Milky Way began in the work of G. A. Shayn and P. P. Dobronravin in 1937-1938, and then was continued in the cycle of works of Ye. B. Kostyakova, who conducted spectrophotometry of bright sections of the Milky Way in the northern and southern sky. The basic result of her investigation is establishing the gradual change of color in the Milky Way with distance from the center of the Galaxy. By analogy with other galaxies this undoubtedly testifies to a relative increase of red stars in the central regions of our stellar system and an intensification of the influence of blue stars in the outer parts of the Galaxy, in its spiral branches. The central part of the Galaxy turned out to be very considerable in size. This investigation had something in common with work on infrared photometry of the Milky Way carried out by S. F. Rodionov, I. G. Frishman and their colleagues (1951). They also showed an increase of the intensity of radiation by the center of the Galaxy, however the center itself included in the observations, and publications of the results are very brief. This work unfortunately has never been repeated or checked.

There is every basis to consider that the Galaxy has a spiral structure. Determination of the type of the Galaxy in many respects relies on the study of its core, inasmuch as the degree of development of the spiral branches and dimensions of the core are in close dependence. Study of the cores of galaxies is of considerable independent interest, especially because in these cores occur processes in many respects still incomprehensible, accompanied by

the ejection of a great quantity of substance into space. Soviet astronomers have repeatedly studied determination of the galactic center (P. P. Parenago, B. V. Kukarkin), however the center, itself, enclosed by a powerful layer of absorbing substance, has remained absolutely unexplored. We can consider that the bright cloud of the Milky Way in Sagittarius belongs to the central regions of the Galaxy. Work of D. Stebbins and A. Whitford (United States) showed that to the north of this cloud is increased infrared radiation. The center of the Galaxy was positively located by A. A. Kalinyak, V. I. Krasovskiy and V. B. Nikonov (1950), who were the first to study the Galaxy using an image converter. Using this new technology they were able to photograph the northern part of the central body of the Galaxy, hidden by interstellar absorbing matter. The cloud in Sagittarius and the again-revealed cloud to the north of it together make up the center of the Galaxy, intersected by a powerful band of absorbing matter. The enormous dimensions of the center and its height above the galactic plane indicate that our Galaxy is apparently a spiral system of Sb type, i.e., has a sufficiently large center and well-developed sprial branches. Unfortunately, further investigations of the center were already being continued outside our country.

For many years here and abroad the search for the spiral structure of the Galaxy has pressed on. The approach to this question is from the most various points of view. One work of J. Oort, presenting a center-anticenter concept of the Galaxy, seemingly showed the existence of two branches, located on both sides of the sun. Parenago tried to use these still insufficient data to judge the movement of the spiral branches. Sh. T. Khabibullin (1949) repeated Oort's work using more contemporary data about the absorption of light. His cut of the Galaxy testifies only to a drop of density from its center. This work could not show spiral branches. B. V. Kukarkin observed that long-period cepheids are positioned in the neighborhood of the sun in elongated bands. He interprets this as an indication of the existence of a spiral branch.

By analogy with other galaxies the best indicators of a spiral structure should be the stars of early spectral classes, H II,

hydrogen ionization regions, gaseous nebulae and early star clusters. An attempt to use early giants was made in 1953 by B. A. Vorontsov-Vel'yaminov; however, the absence of data about absorption of light up to each specific star disallows his considering conclusions as final in any way. I. M. Kopylov used grouping of early stars and also concludes the existence of a series of spiral branches. The basic deficiency of these works is probably that, considering considerable scattering of individual points, the carrying out of spiral branches carries a somewhat indefinite character in time. Very interesting is V. F. Gaze's 1954 attempt to study the spiral structure according to the totality of emission nebulae. In postwar years under the leadership of G. A. Shayn Simeiz began systematic searches for emission nebulae using a fast lens camera. They were rewarded with the discovery of many tens of new nebulae. Their properties, masses, connection with stars exciting the glow of gas were studied in detail. Estimating by the exciting stars the distance to the nebulae, Gaze showed three spiral branches, two of which are behind the sun in the direction of the anticenter and one is near the center of the Galaxy. Further work, which definitized the distance of the nebulae and showed new objects in the southern sky basically confirmed the picture depicted in the study of Gaze. In 1959 B. Ye. Markaryan published an interesting study in which he shows that in the neighborhood of the sun three segments of spiral branches are observed. Spiral branches are formed by accumulations of early O and B1 types; at the same time later accumulations turn out to be indifferent to the spiral structure. Movement of branches according to early accumulations turned out to be the smae as according to the so-called aggregates of Morgan and his colleagues. Further work of V. Becker, T. Schmidt-Kaler and others led to analogous results. Spectrophotometric investigations of the Milky Way carried out by Ye. B. Kostyakova also indicate a spiral structure in agreement with data of other optical methods.

The problem of the spiral structure of our Galaxy still cannot be considered finally solved. The volume in which optical methods can reveal objects characteristic for the population of spiral branches is much too small.

An absolutely new approach to the study of the large-scale structure of the Galaxy was opened with application radio methods. In 1945 H. van de Hulst and in 1948 independently of him I. S. Shklovskiy showed the fundamental possibility of observations of interstellar hydrogen by radio astronomical methods on a wavelength of 21 cm. Soon the radio radiation of hydrogen was revealed and investigated by scientists of Holland, Australia and other countries. Somewnat later the work on radio observations was joined by Soviet astronomers and physicists. Treatment of observations showed that in the Galaxy are extended gas formations located along the circumference with a radius approximately equal to the distance of the sun from the center. These investigations were wholly based on kinematic methods developed in stellar astronomy. In 1955 P. P. Parenago examined the radio observation of the Dutch scientists and obtained a somewhat different picture of the location of the spiral branches.

However, the circular character of the distribution of hydrogen remains common. The basis of similar investigations is defined ideas about the kinematics of the Galaxy. Their change, for example, the introduction of expansion or compression besides rotation can lead to an essentially different picture of the space distribution of gas. This circumstance was ncted by Parenago, who showed that with consideration of negative K-effect spirals from almost circular will be turned into formations more similar to the spirals of other galaxies. This idea was developed by I. L. Genkin, who obtained a more probable picture of the location of spiral branches. Recently the derivation of a law of rotation in the Galaxy according to radio observations, which is the basis for judgements about its sprial structure, has occupied T. A. Agekyan and his colleagues, and also the astronomers of the Tartu Observatory. A new attempt to study the spiral structure is being made by N. S. Kardashev, T. A. Lozinskaya and N. F. Sleptsov, who are examining all accumulated material on the contours of λ 21 cm hydrogen radio lines. They again found that with distance from the center of the Galaxy spirals very slowly unwind and the structure is very close to circular. This and other analogous conclusions are very difficult

to coordinate with the results of optical observations, indicating a severe slope of spiral branches to the radius-vector.

It is not excluded that this contradiction can be removed by assuming that the Galaxy has not two but considerably more spiral branches (A. S. Sharov and Ye. D. Pavlovskaya; Yu. P. Pskovskiy). Curiously, the idea of several spiral branches was expressed probably earliest by Parenago (1955). The disagreement of optical and radio astronomical data about the structure of the Galaxy was repeatedly indicated by Vorontsov-Vel'yaminov. It is appropriate to mention also that in recent years he noted an extraordinarily large variety in the forms of galaxies. Complete rejection of the possibility that our Galaxy is not a simple spiral with two branches, but has a more complex structure is apparently unfounded. This view is ever more widely penetrating astronomical literature.

Study of the shape of the Galaxy is very intimately connected with determination of its basic plane. One method of determining the galactic plane was proposed by Parenago and applied to long-period cepheids. Study of the nucleus of the Galaxy, and also radio emission showed that the former pole of the Galaxy requires a certain correction. The necessity of this definitization was indicated by I. S. Shklovskiy. A new determination of the position of the pole was made in 1955 by T. S. Kirillov. The galactic plane is best determined according to the neutral hydrogen observed practically throughout the Galaxy at huge distances from the sun. However, radio astronomical observations on a 21-cm wavelength showed that the gas disk of the Galaxy is deformed. The basic gas masses at great distances from the sun are clearly outside the Galactic plane — in one hemisphere to one side of it, and in the other to the other side. This effect was investigated in detail by T. A. Lozinskaya and N. S. Kardashev (1962), who explained it by the gas-dynamic interaction of the Galaxy and intergalactic matter. They also investigated the thickness of the gas disk in external regions of the Galaxy and showed that it gradually increases, in certain directions attaining 2 kps.

In the last decade the role of the magnetic field in the Galaxy was clarified. It is obvious that it determines the formation of gas spiral branches. At the same time ideas about formation of galaxies as a result of gravitational condensation of huge masses of gas underwent intensive development. The interaction of condensed and revolving gas masses with the magnetic field for various slopes to the axis of rotation, in the opinion of S. B. Pikel'ner, can lead to the appearance of spiral galaxies with two or several branches. There are no doubts that in the future the spiral structure should be studied in close interaction of ideas of traditional stellar astronomy and ideas of astrophysics and magnetic gas dynamics.

In the 1940's the idea that the Galaxy is not a single system in which objects of various physical types are more or less evenly mixed was finalized. These studies were begun by the Swedish astronomer B. Lindblad, studying stella kinematics. He allowed that the Galaxy consists of a series of subsystems of stars penetrating each other with different space distribution and various velocity distribution. In 1933 K. Bottlinger (Germany) first showed that in the Galaxy are three subsystems, differing in the degree of concentration of objects at the galactic plane and center. Studying visible distribution, he enumerated the types of stars belonging to each subsystem. In 1944 V. Baade (United States) using a 100-inch reflector investigated the Andromeda nebula and concluded that in the galaxies should be two types of population, which he called population I and population II. Simultaneously Kukarkin was studying in detail the space distribution of variable stars and independently of Bottlinger established that they enter at least three components of the Galaxy: flat, intermediate and spherical. The idea of subsystems forces new consideration of the structure of the Galaxy. In connection with this the value of general investigations, when stars are not separated by characteristics, essentially decreased.

In Moscow several studies were made of the star distribution in space. Especially helpful were the variable stars. They are

easily separated from among the constant stars and thanks to the connections between the character of their changeability and luminosity the distance to them can be determined.

Clearly the study of subsystems of variables demands enormous work in cataloging, classification, and deriving statistical connections between different morphologic characteristics. Numerous data about variable stars found a place in the catalogs of variables and stars of suspected changeability (such catalogs are published in Moscow at the order of the International Astronomical Union). For all studied subsystems successful attempts were made to present distribution of objects perpendicular to the galactic along the radius of the Galaxy by formulas analogous to the barometric formula. It turned out that density drop by a factor of e for flat subsystems occurs on 50-100 ps; on the contrary, for spherical subsystems such a density drop is attained only on distances near 2000-3000 ps. In the Galactic plane going toward the center density grows rapidly for spheric subsystems and very slowly for the flat. B. V. Kukarkin examined in detail subsystems of stars of RR Lyrae type, cepheids, stars of Mira Ceti type and certain others; Parenago, Kukarkin and N. F. Florya examined a subsystem of globular clusters; Vorontsov-Vel'yaminov examined planetary nebulae (he repeatedly put together combined catalogs of these nebulae); J. J. Ikaunieks studied red stars; K. A. Barkhatov worked with galactic star clusters, etc.

As I. M. Kopylov established, gradients characterizing density distribution in subsystems along the radius of the Galaxy and perpendicular to its plane, are in a particular interconnection, which makes it possible to estimate one gradient by knowing the other. Some subsystems turned out to be very nonuniform. Objects belonging to the same type and distinguished only by fine morphological peculiarities, showed various distribution in space.

In a number of similar investigations an elegant method proposed by M. A. Vashakidze (1937) and independently by Oort (1938) found wide application. This method permits effectively determining the

change of star densities in various directions, if the distribution of objects along the z-coordinate is established. The Vashakidze-Oort method is used to study subsystems consisting of a sufficiently large number of objects when the statistical approach is valid.

Ideas about subsystems have not just a purely geometric meaning. It turned out that belonging to subsystems is intimately connected with kinematic characteristics of the totality of stars of a given physical type. Knowledge of kinematics in many cases made it possible to imagine the role of stars of a given type in the general structure of the Galaxy, ever if these stars are studied only in the close environments of the sun. Thus, in particular, subdwarfs, forming a spherical subsystem, in the opinion of Parenago play a large role in stellar composition of the external regions of our stellar system, located high above the plane of the Galaxy. This became possible thanks to the general relationship shown by Parenago between velocity dispersion of subsystems and volume density gradient in the direction of the z-coordinate.

In the works of Parenago (1950-1960) dedicated to so-called practical stellar dynamics comparison of kinematic parameters of subsystems with conclusions from the theory of a stationary galaxy was widely used. In the first place this had a relationship to study of stellar motions themselves. However, theory permitted obtaining formulas connecting kinematics with parameters of space distribution, and on the basis of study of stellar motion obtaining interesting conclusions about the general features of the structure of the Galaxy.

Until now we have touched only on works directly following from observation. It is necessary to mention also works of another kind — theoretical research, in which models of the distribution of masses in Galaxy are constructed and thereby basic features of the structure of our stellar system are described. The founder of similar works in our country was P. P. Parenago, who in 1950 published the first and in 1952 the second study of galactic potential. Using the formula of angular velocity in the Galaxy, he obtained the expression for

potential in the galactic plane, and then generalized it in certain simplifying assumptions for the case when the z-coordinate is different from zero. The solution to Poisson's equation permitted constructing the distribution of masses in the Galaxy, in general similar to that obtained from the investigation of other stellar systems.

Parenago's potential found wide application in a cycle of works by G. M. Idlis, who constructed a theoretical model which made it possible to describe practically all stellar-dynamic properties of the Galaxy from a single point of view. This includes estimates of dimensions, mass and density of the galactic nucleus, and an estimate of the density of substance in the environments of the sun, total mass of the system, its dimensions and distribution of density of different components, etc. The theoretical conclusions Idlis applied to the analysis of other stellar systems, for example the Andromeda nebulae, in general similar to our Galaxy.

One of basic centers in our country where now work is being conducted on the creation of theoretical models of the Galaxy is the Tartu Observatory. In 1952 G. G. Kuzmin in his own theory presented the Galaxy in the form of a nonuniform ellipsoid, and in 1956 proposed a generalized spheroid model, consisting of a multitude of separate spheroids inserted into each other. In 1965 S. A. Kutuzov examined another model, proceeding from the sufficiently general law of rotation of the Galaxy and other assumptions. During the construction of theoretical models it is necessary to have the most exact parameters characterizing the Galaxy. These parameters are interconnected by dynamic relationships and are not independent. In recent years Estonian astronomers have given much attention to obtaining a coordinated system of galactic parameters (Ya. E. Eynasto, S. A. Kutuzov).

From the beginning of the 1950's P. N. Kholopov and his colleagues have studied the structure of star clusters. An account of the obtained concrete results goes beyond the framework of a section about the structure of the Galaxy as a whole. It is necessary to mention

here only one aspect of these investigations. The work showed with certitude that star clusters have extraordinarily extended external regions; their dimensions compose several tens of parsecs. In spite of the small star density, the general mass of such coronas exceeds by a few times the mass of those stars which are in clusters directly visible on photographs. In such a case the clusters constitute a sufficiently noticeable structural component of the Galaxy.

A still bigger component is the star clouds, similar to those which received so much attention by B. A. Vorontsov-Vel'yaminov during the study of other galaxies. One such object must be considered the Local system, investigated in pre-war years by R. V. Kunitskiy, M. A. Vashakidze, Ye. K. Kharadze and others.

Study of the physics of interstellar matter has enriched our understanding of the role of gas in the structure and evolution of the Galaxy. From the point of view of the Galactic structure the most important are the conclusion of S. B. Pikel'ner that gas creates a huge corona surrounding a flat subsystem in which more dense gaseous nebulae are concentrated, and also G. A. Shayn's study of the magnetic field of the Galaxy by forms and distribution of gaseous nebulae in it. These questions are examined in greater detail in the section "Interstellar Matter and Planetary Nebulae." In the section "Radio Astronomy" results of radio astronomical investigations of the Galaxy are reflected more fully.

For the past 50 years study of the structure of the Galaxy in our country advanced considerably. A series of results attained by Soviet astronomers forever entered the basic fund of contemporary knowledge about our stellar system. Further development in the construction of large telescopes and radiotelescopes, introduction of new physical methods of investigation, growth of the qualification of our scientific cadres undoubtedly will lead to still greater achievements in the study of the Galaxy.

EXTRAGALACTIC ASTRONOMY[1]

Extragalactic astronomy at present is one of the most captivating and burgeoning areas of science. The cause is not only that in our time the possibilities of studying other stellar systems (galaxies) and comparing them with our stellar system (the Galaxy) have strongly increased. Study of the world of galaxies, their clusters and also the whole observable totality, the Metagalaxy, agitates us with the question of the finiteness or infinity of the Universe, the growth of galaxies, the most ancient history of our stellar system, the origin of chemical elements. Galaxies — the most distant objects known to man, the most grandiose and massive of learned systems. The development of hypotheses about the origin of our earth leads to the galaxies. Long ago it was understood that this problem cannot be solved outside the framework of the story of the whole solar system. Hypotheses about its origin led to the question of the origin of stars, then stellar systems — galaxies; next stands the problem of the origin of the Metagalaxy.

In the last few years data have been obtained indicating that in the scale of galaxies there are properties and phenomena whose nature is still unknown to us.

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[1]Work on the study of our Galaxy and radio galaxies is discussed in the sections "Structure of the Galaxy" and "Radio Astronomy" of this book.

Finally, the youngest area of astronomy – radio astronomy – which, studying the radio radiation of celestial bodies, very recently met the mysterious "quasi-stellar radiation sources" (quasars). These objects are possibly a galaxy in a special state. Separated from us by monstrous distances of the order of 10 billion light years, they lie on the boundary of access now for the study of part of the Universe.

Foggy spots were discovered and described long ago. However, ignorance of distances, and consequently also dimensions of the nebulae for a long time did not permit establishing their true nature and dimensions.

A prerequisite to successful sounding of the depths of the Universe was the discovery of Levitt (United States), who in 1912 found that for one of the types of periodic variables – the cepheids – in the Small Magellan Cloud periods of change of brightness are intimately connected with the apparent stellar magnitude of stars. Inasmuch as all stars of this system are separated from us by distances of one order, it followed that the period of change of brightness of the cepheids depends on their true luminous intensity, characterized by an absolute magnitude.

The following year E. Hertzsprung (Denmark) established the zero-point of the period-absolute magnitude dependence, i.e., clarified what absolute stellar magnitude corresponds to a given period (several galactic cepheids close to us were used; their distance was estimated by proper motions). From comparison of the absolute stellar magnitude of the cepheids with the apparent stellar magnitude of such stars in the Small Magellan Cloud, Hertzsprung estimated the distance to it at 30000 light years. This showed that the Small Magellanovo Cloud is 100 times further away than the most distant stars, whose distance from us can be determined by the direct trigonometric method.

In 1916-1918 Shipley (United States) definitized the zero-point for cepheids. Showing cepheids in the composition of globular

clusters, he determined the distance to the latter and clarified that the center of their system is the center of all our Galaxy. The size of the system of globular clusters determines the approximate dimensions of our Galaxy. According to recent data its diameter is around 100000 light years, and the distance from us to its center is around 30000 light years.

Copernicus showed that our earth is not alone. It is one of several planets of a solar system. Later it was understood that the sun is only one star among others. E. Hubble (United States) in 1925 finally proved that even our Galaxy is one of billions of galaxies, and thus infinitely opened the boundaries of the knowable world (he found cepheids in the spiral Andromeda nebula, and then proved that in size and composition it is very similar to our Galaxy).

Thus extragalactic astronomy appeared. Until recently it developed almost entirely in the United States, since the necessary observations could be carried out mainly only with the help of the large contemporary telescopes and in good atmospheric conditions, which California has.

First Period of Study of Galaxies (to the Mid-1950's)

In the USSR, as in the rest of Europe, in the absence of the required conditions it was possible to use only photometric and colorimetric methods of observation, and then only for the brightest and rather well-studied galaxies. Therefore in the collection, dedicated to progress of astronomy in the USSR for 15 years, the word "nebulae" was included in the section about photometry and colorimetry. Its author, who was not interested in nebulae and star clusters, dedicated a half page to it in all, not mentioning the extragalactic nature of nebulae. For this period (1920's-1930's) the sole, but interesting, work was that of A. V. Markov (1929). He attracted attention to absolute photometric measurements, which became widely used only at the end of the 1950's.

Up to the mid-1950's studies of galaxies in the USSR were conducted episodically and did not have great cycles, with the exception of the work of M. S. Eygenson (1906-1962) at Pulkovo and also M. A. Vashakidze (1909-1956) at the Abastumani Observatory, where there was a partially hand made reflector with a mirror 32 cm in diameter. Vashakidze photographically determined the color indices of several hundred galaxies. In principle such work has great value, since by the color of a galaxy it is possible to judge the composition of its star population, which for various galaxies is different. Unfortunately, the photographic method is insufficiently exact in the case of eroded objects, especially when their color is determined for the entire galactic image as a whole. Vashakidze photographically studied the polarization of close galaxies as well. Being very small and localized only in their equatorial plane, polarization unfortunately was not determined photographically with the proper accuracy needed to study the properties of the dust producing the light polarization in galaxies. After the work of Vashakidze (1940-1945) abroad began the use of either integral colorimetry of galaxies — more exactly, the photoelectrical method — or photographic colorimetry, but by large-scale photographs, constructing exact isophots according to images of the large galaxies. In the USSR similar to the work of Vashakidze was the work of F. I. Lukatskaya (1943) on distribution of color in the spiral galaxy M 51. N. N. Sytinskaya in the same year investigated the distribution of absolute luminosity in several of the nearest galaxies.

An especially extensive cycle of works using chiefly statistical methods was carried out by M. S. Eigenson from 1932 to 1943 at the Pulkovo Observatory. Basically they are summarized in his extensive 1935 monograph "The Great Universe." Abroad the first similar monograph (E. Hubble) was published a year later. The same systematic account, now of an immeasurably greater quantity of material, Eigenson gave in his second monograph "Extragalactic Astronomy" (1960).

Eigenson in 1936-1938 studied the absorption of light inside galaxies and between them. In the first case he found the absorption of light equal to $0\overset{m}{.}6$ in the polar direction and $2\overset{m}{.}2$ in galactic plane, while intergalactic absorption (according to his data, which agree with foreign investigations) appeared insignificantly small. On the basis of greater material he confirmed the randomness of the distribution in space of the directions of the axes of rotation of spiral galaxies, the imaginary ordering of which relative to our Galaxy had previously led certain astronomers (D. Kh. Reynolds) to negate the theory of the "insular universe." Up to the middle 1950's Eigenson was the most active researcher of galaxies and had published around 15 works.

In the works of 1945-1947 I. M. Gordon (Kharkov) was one of the first to investigate the distribution of cepheids and the dispersion of their visible brightness in the nearest galaxies, especially in the Magellan Clouds, obtaining as a result estimates of the light absorption in these galaxies.

Hydrogen luminescent nebulae in galaxies in 1952-1954 was detected at the Crimean observatory by G. A. Shayn and V. F. Gaze from small-scale photographs on a very fast-lens astrograph. They first established that the masses of complexes of gaseous nebulae in certain of the nearest galaxies can be tens of thousands of times greater than the sun. There are apparently no such powerful gas complexes in our Galaxy. The starting point for these works of Crimean astronomers was not the study of galaxies as such, but the study of gaseous nebulae in general.

Second Period in the Study of Galaxies (From the Mid-1950's). Morphology of Galaxies

From the middle 1950's the work of Ambartsumyan and Vorontsov-Vel'yaminov set the basic direction of extragalactic astronomy in the USSR — study of the morphology of galaxies, which was developed mainly at Moscow and Byurakan. The Byurakan direction of works is furthermore characterized by its close connection with the hypothesis of Ambartsumyan about the joint origin of stars and diffuse matter from dense or, perhaps, superdense prestellar substance.

Extensive material on the photometry and colorimetry of galaxies was published in 1955 by D. Ye. Shchegolev, using the meniscus telescope of the Maksutov system, mounted shortly before this in Alma Ata. This instrument, 50 cm in diameter, has the considerable aperture ratio necessary for similar investigations. Shchegolev (with more material) confirmed the earlier conclusion that the spiral branches of galaxies are bluer than their central regions. This means that with distance from the center in the spiral branches that part of light from hot, young stars increases. He showed also that the radiation of spiral branches is small in comparison with radiation of the nucleus and glow of the disk between branches. Although Shchegolev's photographic scale was still too small and details in the structure of the galaxies could not be distinguished, in the list of photometrically studied galaxies in the American 1959 monograph Shchegolev's objects still make up the majority. Abroad detailed photometry of galaxies also began only from the end of the 1950's.

Recently Shchegolev's work was continued here chiefly at Byurakan. Very detailed colorimetry of a series of large galaxies carried out by B. Ye. Markaryan and A. T. Kallogylyan with colleagues at the end of the 1950's brought them to a conclusion concerning the relationship of the light contribution of white and yellow stars at different distances from the center different in various galaxies, and concerning the role and distribution in galaxies of selective light absorption. Thus it was shown that the variety in composition of various galaxies is more than was assumed earlier. These works were the beginning of detailed study of galaxies. They introduce much that is new to the former, simplified and schematic ideas about their nature.

Considerable attention at the Byurakan Observatory is given to peculiar galaxies, set off by mysterious features. Of these there is special interest in M 82, in whose central part phenomena recently were revealed treated as a gigantic explosion as a result of which gas streams are ejected, moving at speeds near 1000 km/s. This galaxy constitutes a source of increased radio emission, but

its yellowish color contradicts spectral class found by the characteristic hydrogen absorption lines and peculiar to white stars. B. Ye. Markaryan (1963) separated and investigated other galaxies having similar spectral criteria anamalous for their type. He also concluded the existence of additional nonthermal radiation in the violet region of the spectrum. It perhaps is the so-called synchrotron radiation, which also explains the radio emission of radio galaxies.

An unexpected and interesting explanation of the origin of hydrogen absorption lines in galaxies of type M 82, where hot stars apparently do not exist or are small, was given by G. A. Gurzadyan. He showed (1963) that hydrogen absorption lines can appear if in the galaxy there is much neutral free hydrogen, absorbing the light of stars which are immersed in it. Such an explanation, also finding sympathy abroad, apparently, solves the puzzle.

A. A. Kalloglyan from his own measurements found that for intersected galaxies with a bright connecting piece surface brightness is almost constant.

As already was said, the work of the Byurakan astronomers basically developed the idea of Ambartsumyan about the origin of all stars and nebulae as a result of gradual decay of presetellar superdense bodies. Ambartsumyan started from the development of ideas about the appearance of hot stars by means of disintegration of massive superdense, but invisible bodies into smaller masses and further transformation of their parts into stars and gas. Thus according to him inside one association of superdense bodies there nonsimultaneously appear associations of hot stars. The appearing stars will form a system with positive energy and, insufficiently held by mutual gravitation, in time they part in space, are cooled and are lost in the general mass of stars.

In 1956 Ambartsumyan extended this conception to double and multiple galaxies and their clusters. He showed that groups of galaxies usually are built as stellar systems of the type of the Trapezium of Orion and therefore, as follows from statistical

Victor Amazaspovich
Ambartsumyan

mechanics, are unstable and must disintegrate. For a series of groups and clusters this was (after certain doubts) confirmed by a number of foreign researchers and now scarcely encounters objections.

The conclusion concerning instability of separate groups in the form of chains and clusters of galaxies was confirmed also by Byurakan astronomers — B. Ye. Markaryan, T. D. Karachentsev and others. His own conclusions, in particular the joint appearance of clusters of galaxies (inasmuch as the number of observed multiples of systems exceeds that expected in the case of dissociative equilibrium), Ambartsumyan grounded in extensive works of 1958 and 1961.

Radio galaxies, appearing as supergigantic systems, are examined according to Ambartsumyan as systems in which nuclear fission occurs, leading subsequently to the separation of one galaxy

into two. Interacting galaxies are also considered to be systems in the process of their division, and the cross connections between them are the result of such separation.

Radio emission is one of the criteria of activity of a nucleus; another are attachments, similar to ejections from nuclei (in NGC 4486, 3561 and IC 1182), outflow of neutral hydrogen from the nucleus of our Galaxy, outflow of ionized gases with enormous velocities from nuclei of so-called Seyfert galaxies.

In the majority of galaxies it is possible to see the coexistence of different subsystems (most frequently spherical and flat) with a common center in the nucleus of the galaxy, but now and then and with different centers. Ambartsumyan considers that as a result of the ejection of substance from superdense nuclei and their division, there appear at various times internal subsystems, globular clusters, galaxies — satellites of smaller mass and luminosity, and also groups of galaxies and their clusters.

Newly forming systems must consist of young (blue) stars.

Therefore any attachments of nuclei and satellites of galaxies of bluish color are considered as recent. Their blue color is treated also as a possible criterion of the presence of synchrotron radiation, the observable monstrous concentration of which, in the opinion of Ambartsumyan, possibly will demand further generalization of the laws of conservation of energy and substance.

In the United States in 1961 a conference was organized for discussion of stability of groups and clusters of galaxies. At the conference the majority of researchers was inclined to the acknowledgement of instability of groups of galaxies and to conclude the possibility of finding new cases where instability exists. The discovery of quasi-stellar radiation sources with some attachments and the observation of phenomena similar to explosion in the nucleus of irregular galaxy M 82, can be examined as confirmation of the cosmogonic concepts of Ambartsumyan, although the majority of

astronomers continues to assert the point of view about the appearance of stars from diffuse matter.

V. A. Ambartsumyan referred to as superassociations especially large and bright complexes of hot stars and gaseous nebulae such as 30 Doradus in the irregular galaxy of the Large Magellanic Cloud. Jointly with his colleagues (R. K. Shakhbazyan and others) he estimated by photographs obtained at the observatory in Byurakan and by other materials the number of superassociations and their absolute magnitude in approximately 200 spiral and irregular galaxies. They found that superassociations are encountered chiefly in supergigantic galaxies of type Sc (with a small compact nucleus and widely developed spiral branches), and also in certain irregular galaxies with considerably lower luminosity.

Comparing the abundance of young hot stars and strong fragmentation of neutral hydrogen in the Large Magellanic Cloud with the more uniform structure of hydrogen at greater density and less intense star formation in the Small Magellanic Cloud, Ambartsumyan in 1963 concluded that every superassociation appears from one prestellar body, probably superdense, by means of its splitting. Its parts subsequently nonsimultaneously divide into stars and separate gas. This conception is part of the general hypothesis of Ambartsumyan about the joint origin of stars and diffuse matter from superdense prestellar bodies (we meet this hypothesis later in the section "Stellar Cosmogony").

From 1955 began the cycle of works of B. A. Vorontsov-Vel'yaminov on the morphology of galaxies. Based on published photographs, he found that in the spiral system M 33 the location of "dust channels" of dark matter resembles a lightning trail. His comparison for M 33 and our Galaxy of dark channels with rows and chains of hot giant stars, discrete dark clouds — with star clusters and globules — with individual stars is a strong argument in favor of the "coagulation" of stars from diffuse matter.

The presence of diffuse matter in spherical stellar systems

was proven also (1957), the thickness of dust layers in spiral galaxies was investigated (1963) and for the first time (1958) the mass of gas in galaxies with wide spectrum emissions was determined ("Seyfert galaxy").

The similarity he found of the spectra of such galaxies with the spectra of certain radio galaxies, advanced as an argument against the fashionable interpretation of the latter as a pair of colliding galaxies, obtained new confirmation when it was clarified that the two Seyfert galaxies indeed are radio galaxies. From 1964 E. A. Dibay and V. I. Pronik started more detailed study of the spectra of the Seyfert galaxies on the 125-cm reflector mounted at the Crimean Station GAISh in 1963.

Until now the existence for many galaxies of spiral branches and their undoubtedly prolonged existence has been a puzzle. This seemed especially strange if one were to consider that in galaxies there exists differential rotation, the angular velocity of which is a function of distance from the center of the galaxy, which had to lead to "dispersion" branches.

B. A. Vorontsov-Vel'yaminov (1955) showed that galaxies with a cross connection can rotate only as a solid, which before had not been noted. He showed that the internal parts of the usual spiral galaxies cannot rotate by this law, derived for our Galaxy according to the motions of the stars nearest us, distant from the center, and extrapolated onto the central region. The spiral branches of galaxies would change too fast. Thus, the region of clearly visible spiral structure should be a region whose rotation is close to that of a solid.

Differential rotation becomes noticeable where the features of spiral structure are lost. Our sun is in such a zone and therefore probably in its environments it is not possible to confidently outline spiral structure, where it apparently is already lacking. Numerous curves of the rotation of galaxies obtained later confirm there conclusions.

In the chain of development of morphological study of galaxies lies also the study of clusters in their spiral branches. These clusters are star clusters and associations of hot stars, accompanied usually by complexes of gaseous nebulae. In Moscow the colleagues of B. A. Vorontsov-Vel'yaminov composed catalogs, studied the location of such clusters in M 33 and estimated their brightness (1955-1959).

In 1963 under his leadership photometry (without colorimetry) of galaxies was started, partially from large-scale photographs on the Crimean 125-centimeter reflector (GAISh). Unfortunately, the light background of the sky in Crimea hinders the study of weakly luminescent outskirts of galaxies. During the study of such foggy objects in visible rays of light the sky background is much more of a hindrance than during the study of stars. This limits also the value of photographing galaxies using the image converter, which was started in 1962 at the Crimean Astrophysical Observatory. A group of A. B. Severnyy, V. B. Nikonov and K. K. Chuvayev obtained photographs of many galaxies through interference light filters with an exposure of only several seconds. Using photography many hours would be needed for this.

With this new method the Crimean scientists could distinguish in galaxy regions in which radiation of stars predominates and regions with a predomination of the radiation of interstellar hydrogen. They could use for these observations a newly installed telescope with a mirror diameter of 2.6 m.

At the completion of many years of study by the Moscow group of astronomers, directed by B. A. Vorontsov-Vel'yaminov, Part I of the Atlas and Catalog of Interacting Galaxies was published in 1959, and then four volumes of the "Morphological Catalog of the Galaxies" (1962-1967).

The Morphological Catalog of the Galaxies was composed by B. A. Vorontsov-Vel'yaminov, A. A. Krasnogorskaya and V. P. Arkhipova based on the Palomar Atlas of the Sky. It contains detailed data

Irregular galaxy Messier 82 (NGC 3034). Photograph obtained with 125-cm reflector GAISh (Crimean branch) 9 March [illegible] by E. A. Dibai.

on 30,000 galaxies and has been designated to replace the obsolete New General Catalog (NGC) of Dreyer [Translator's Note: exact spelling of name not known] (England, 1898-1908), containing around 13,000 clusters of stars, gas and dust nebulae and galaxies, true nature of which then was still not known. Partly the insufficiency of classification E. Hubble (based entirely on three hundred objects), and also other causes impelled the compilers to replace classification of galaxies by a description of them using symbols characterizing the elements of their structure.

From the times of V. Herschel as a queer thing of nature now and then pairs of galaxies united by connecting pieces having unusual thin branches[1] were noted. These characteristic parts B. Lindblad and P. O. Lindblad explained by tidal phenomena.

Vorontsov-Vel'yaminov expanded the idea about similar pairs and groups of galaxies, calling them interacting. He found hundreds of them on photographs in the Palomar Atlas of the Sky, published in the United States, and attracted much attention to them. It was shown that they compose several percent of the total number of galaxies, have repeated forms of interaction, close radial velocities of components, which apparently are genetically connected, and are not the result of random encounter. The impossibility of explaining their deformation by tidal phenomena was shown and the idea was expressed that they are either caused by magnetic forces or by still unknown forms of interaction. In 1964 Vorontsov-Vel'yaminov observed for single galaxies many phenomena indicating that the structure of flattened systems is controlled by a field of forces similar to magnetic.

Hoyle (England) and the Burbidges (United States) stressed that Hubble attracted attention to the study of regular galaxies

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[1]Meanwhile Herschel himself, first discovering similar objects in 1783-1785, considered their phenomenon rather widespread and regular. He explained them by the separation into parts of such nebulae in which in the course of general evolution of cosmic matter under the impact of gravitational force several centers of thickening randomly appeared. Conclusions of Herschel were subsequently absolutely forgotten. — Ed. note.

and that the appearance of the "Atlas of Interacting Galaxies" began a new direction of study in extragalactic astronomy. In the five years after the "Atlas" appeared various countries published many works with a theoretical discussion of the role and origin of interacting galaxies and their cosmogonic value. Astronomers of the United States allotted a great deal of time to more detailed study (using the largest telescopes) of interacting galaxies by means of photographing, colorimetry, spectrography and searches for the radio emission of such systems.

One of the most important questions connected with the morphology of galaxies is the accepted scale of distances to them. This involves conclusions concerning dimensions and luminosity of galaxies and their distribution in space. In our country this question in recent years has been studied by Yu. P. Pskovskiy (Moscow, 1960 to 1963). The scale of distances has been intensively discussed for the last 10 years abroad. Pskovskiy did not agree with the scaling of van den Berg for the classes of luminosity of galaxies according to the red shifts in their spectra, and rescaled their luminosity by types of galaxies in the classifications of Morgan and de Vaucouleurs. Departing from the accepted distance to the cluster of galaxies in Virgo, he determined the average luminosity for separate subtypes of galaxies and the distance to the nearest galaxies, and also the distance to close galaxies with respect to the cepheids taking into account the absorption of light. He observed certain effects of selection in the data of observations, studied distribution of the nearest galaxies in space and anisotropy in their red shifts, trying to investigate its possible causes. Along the way incidentally he noticed certain correlations of color and luminosity of spiral galaxies.

It is necessary to say that work on these questions in world literature appear and are examined on the basis of rapidly definitized data of observations almost yearly.

In certain cases the indicators of distances to galaxies can be supernovae flaring in them. For this it is necessary to know

their average luminosity better, which Yu. P. Pskovskiy also definitized. He found that a few supernovae flare chiefly in the gigantic galaxies once in 100 years, and others once in 600 years in galaxies of various luminosity.

Kinematics of Galaxies

In the 1930's it was considered that the direction of solar motion in our Galaxy relative to other galaxies coincides with the direction of its motion with respect to globular clusters, slowly turning near the center of our Galaxy. Only the last has been determined.

In 1938 B. A. Vorontsov-Vel'yaminov and O. P. Kramer determined solar motion with respect to galaxies with known radial velocities. The "red shift" of lines in their spectra – displacement, growing with distance to the galaxy – was thoroughly considered. Thus for the first time the direction of solar motion with respect to galaxies was established. This work explained the apparent increase of random velocities of galaxies with distance to them by the growth of measurement errors. Furthermore, the true average natural velocity of the galaxies was estimated – of the order of 800 km/s. In further investigations this value did not change essentially.

Apparently, the first thorough theory of kinematics of the Metagalaxy was developed in 1952 by K. F. Ogorodnikov (Leningrad). Using his own method for the kinematics of centroids, he showed that the Metagalaxy is not in a state of only isotropic expansion, as had been assumed earlier, and showed rotation of the nearest parts of the Metagalaxy, indicating a direction to the center of rotation – to the constellation Virgo. The conclusion concerning differential rotation of the Metagalaxy – rotation of a certain totality of galaxies with center in the Virgo nebula – shortly before that had been reached by the American astronomer V. Cooper-Rubin.[1] In

[1]Location of these revolving systems for K. F. Ogorodnikov and V. Cooper-Rubin, however, does not coincide.

subsequent works G. de Vaucouleurs confirmed both the very existence of a certain hypercluster of galaxies with center in the Virgo nebula and its rotation.

I. L. Genkin in 1962 (Moscow) showed that in our Galaxy there apparently exists radial compression, maintaining its branches in the form of a logarithmic spiral. This effect he also suspected for the two spiral galaxies nearest to us.

Dynamics of Galaxies

K. F. Ogorodnikov summarized his cycle of works on dynamics of the galaxies (1948-1958) in the monograph "Dynamics of Stellar Systems" (1958). He took the idea of "dynamically definable D-systems," for which relaxation time is small as compared to the period of rotation and three parameters are assigned: mass, sum of energy of stellar motion and moment of rotation. The theory allowed the author to propose a dynamic classification of systems. For D-systems in the most probable state, rotation will be "solid body." Density in each system is constant and proportional to angular velocity. Therefore the theory of equilibrium of a revolving uniform liquid can be applied to them. Then Maclaurin ellipsoids of the first kind correspond to elliptic galaxies and nuclei of spiral. Maclaurin ellipsoids of the second kind, flattened, correspond to spiral, and Jacoby ellipsoids to needle-shaped galaxies. Their destruction leads to formation of galaxies with a cross connection. The origin of annular structures is explained in the same way. Consideration of a galaxy as a continuous medium, according to Ogorodnikov, is applicable only to its main body. The spherical corona of galaxies plays as it were the role of the walls of a vessel in the theory of gases and does not gravitationally affect the main body.

Later K. F. Ogorodnikov on the basis of works on the morphology of galaxies was inclined to the idea that in the formation of galaxies besides gravitational forces explosive and magnetic forces must also participate. This opinion was also reached abroad. Attempt to create a gravitational-magnetic hypothesis of the origin

of various galaxies was undertaken in 1965 by S. B. Pikel'ner (Moscow).

A series of works on the evolution of rotating, gravitating spherical systems in 1958-1962 was published by T. A. Agekyan (Leningrad). He studied systems stationary in a field of regular forces and nonstationary in a field of irregular forces. During radial oscillations of stars near the center on the early stage of evolution should be intense dissipation, but the already small rotation decreases. The author considers that data of observations on the compression of stellar systems, concentration and number of stars in them confirm his theory. Agekyan studied also conditions for the transition of stable groups of galaxies into unstable, and furthermore found that flat and spherical systems evolve without passing into each other.

I. L. Genkin in 1963 developed a theory of nonstationary stellar systems, including conclusions of the theory of the stationary galaxy as a special case. He explained a series of regularities actually observed in the galaxies and on the whole considerably developed this section of classical stellar dynamics.

G. M. Idlis in 1959 determined the masses of the Magellanic Clouds and their motion and advanced a hypothesis about their origin as a result of (assumed) collisions of our Galaxy with galaxy NGC 55, in the group of large galaxies of the southern sky. Rotation of the Magellanic Clouds is being studied intensively abroad.

Statistics of the Distribution of Galaxies in the Sky

This question leads to clarification of the picture of space distribution, which is important for both cosmogony and cosmology.

V. A. Ambartsumyan in 1940 and 1951 derived an equation to establish the influence of fluctuations in the distribution of dark nebulae of the Milky Way on the visible distribution of galaxies. His pupil T. A. Agekyan generalized this equation and showed that

it is possible to divide parameters — on one hand, those characterizing the patchiness of dark nebulae, and on the other fluctuations in the distribution of galaxies. He found an average absorption of light in clouds from 0.25 to $0^m.85$ and a predominance of small groups of galaxies, containing around eight members.

We saw that from the middle 1950's, especially from 1960, extragalactic investigations in the USSR unfolded on a wide front and much more intensely than in other countries of Europe. We have advanced many fundamentally new ideas, which have attracted the attention of scientists in other countries. Equipping Soviet observatories with telescopes of high and middle power makes possible the development of these ideas on a natural observation base.

DYNAMICS OF STELLAR SYSTEMS

The dynamics of stellar systems appeared as the theory of dynamic structure and evolution of the totality of a large quantity of gravitational material particles. It would seem that knowledge available to science from the second half of the XVIIIth Century - since T. Wright, E. Kant, Lambert - would be sufficient for this new branch of astronomy. However, the appearance of the dynamics of stellar systems "lagged" by more than a century. During that time a huge quantity of new, unrelated observation data was accumulated; in some measure they are inevitably erroneous; in many cases they are contradictory. This material has not yet been mastered; it can even be that it is being supplemented by new fictions, erroneous results and errors faster than the old are overcome. Not without reason already in our days was expressed opinion (Kort, Finlay-Freudlich, FRG) about the impossibility of logically noncontradictiory statistical mechanics of a stellar system.

Actually, contemporary dynamics of stellar systems is not an orderly, logical construction of a type of phenomenological thermodynamics or theory of relativity, but a totality of ideas, particular theories, facts, reasonings, hypotheses, conclusions and postulates, sometimes united by only a common direction and object of investigation. It is absolutely obvious that at least some of these (even basic) elements of the dynamics of stellar systems are contradictory.

Within the bounds of the dynamics of stellar systems there still

are no conventional and logically clear general internal criteria, a totality of noncontradictory initial positions which would permit judging the measure of truth of a result in a system of logical bases of theory. The criterion of "external justification," "agreement with observations" frequently turns out to be very stretchable, slipshod.

The contribution of Soviet astronomers to the dynamics of stellar systems must be estimated taking into account what was said. Concretely this means that apparently the biggest value in the contemporary state is not with detailed quantitative developments of models of the galaxy, etc. Much more important is the discovery of least particular connections between separate elements of theory (including and "negative connections" — mutual contradictory nature and others).

Considerations promoting establishing connections and analogies of any ideas or objects of the dynamics of stellar systems with the concepts of adjacent (and even farther from it!) branches of knowledge are important. The detection of new, previously unknown qualities and properties of a stellar system is also important. Especially valuable are results promoting the appraisal of the area of validity of basic initial positions and axioms of theory.

The dynamics of stellar systems due to the classical nature of its apparatus, methods and prerequisites is at first glance a conception close in spirit to the epoch of classical physics. Nevertheless, questions of evolutionary character appear with probably no less necessity than in the "evolutional" region proper of astronomy — cosmogony. Actually, "expelling" from a stellar system all physical processes, "removing" from it the interstellar matter and force fields (except the gravitational), "turning" stars into classical gravitational material particles, we would arrive at a picture of a system where cosmogony has no place. However, this maximum schematized stellar system would not be within the framework of the idea of a stationary, undeveloping world.

The fact is that itself the interconnection of N >> 1 interacting

particles in a "stellar system" should lead to the appearance of statistical regularities, "thermodynamically irreversible," i.e., effects evolutionary in their very nature, even neglecting physical processes in the stellar system ("dynamic evolution").

Possibly, partly because strict and consecutive formulation of the stellar-dynamic problem involved almost inevitability evolutionary concepts, the dynamics of stellar systems appeared not in the XVIIIth, but only in the XXth Century. The actual historical development did not go from "stellar-dynamic statistical mechanics" to the kinetic theory and thermodynamics, but, conversely, from (developed much later and absolutely independently of astronomy) the statistical concept in physics — to astronomy. Actually, after Herschel, who closely approached the dynamics of stellar systems in the XVIIIth Century, during practically all the XIXth Century we can note only single and fragmentary — although important — results of stellar-dynamic character (Medler, M. A. Koval'skiy, middle XIXth Century).

In prerevolutionary Russian science there was not only no stellar-dynamics but even no traditions favoring development of this direction. Outstanding results in Russia in the region of mechanics, mathematics, physics and astronomy pertained to other areas of theory and created no soil for the appearance and development of stellar dynamics. At the same time abroad at the beginning of the XXth Century there were much more favorable conditions for conception of the dynamics of stellar systems. Here worked a number of outstanding astronomers and physicists whose circle of interests turned out to be very close to those characteristic for "stellar-dynamic thinking": Ya. Kapteyn (Holland), J. Jeans, A. Eddington (England), K. Schwartzchild (Germany), K. Sharl'ye (Sweden) and others. These men took the first steps leading to the dynamics of stellar systems as an independent branch of astronomy. This was the discovery of "two streams" of stars by Kapteyn in 1904 and the interpretation by Schwartzschild in 1907 on the basis of the hypothesis of "ellipsoidal velocity distribution" — a hypothesis penetrated by the spirit of the molecular-kinetic conception. It was the derivation of the "fundamental

equation of the dynamics of stellar systems," rendered a special case of the general kinetic Boltzmann equation (J. Jeans, 1915), and also the first appraisals of relaxation time – in other works, characteristic time of the dynamic evolution of the galaxy as a result of stellar approachs (J. Jeans, K. Sharl'ye, 1915-1916) and others.

In our country the dynamics of stellar systems did not attract the proper attention for a rather long time. At the same time the West continued its rapid development. It is sufficient to mention the detection of asymmetry in stellar motions by G. Stromberg (Sweden) (1922-1924), Oort's discovery (Holland) of rotation of the galaxy and creation of the theory of galactic rotation and the general theory of a stationary stellar system (second half 1920's) Lindblad's (Sweden) creation of a kinematic theory of galactic subsystems and theory of spiral structure at the end of the 1920's and beginning of the 1930's.

First Important Steps in the Dynamics of Stellar Systems in the USSR. Elements of Kinematics and "Practical Dynamics"

Remarkable stellar-dynamic investigations, in particular works dedicated to stellar-dynamic consideration of spherical stellar systems, took place in the 1920's in our country.

In the 1930's in the Soviet Union there were stellar-dynamic studies which were fully comparable in results with the investigations of foreign astronomers in this area at that time. For the first time names of Soviet astronomers joined the ranks of the names of leaders of world dynamics of stellar systems. This appeared already in the actual terminology in this region of astronomy ("Ogorodnikov-Milne kinematics," Ambartsumyan's mechanism for the disintegration of star clusters," etc.).

A considerable contribution of Soviet astronomers in stellar dynamics was K. F. Ogorodnikov's (beginning of 1930's) general kinematic theory of an arbitrary system of moving material points

(includes not only stars, but also galaxies in the metagalaxy), This was a considerable improvement of apparatus and methods of stellar kinematics. Development of this area quickly put it beyond the framework of pure kinematics, leading [thanks to works of both K. F. Ogorodnikov and especially P. P. Parenago (1906-1960)[1]] to the creation of a division in the dynamics of stellar systems, which Parenago called "practical dynamics of stellar system." Being at the meeting point of stellar kinematics, statistics and the problem of concrete structure and motions in the galaxy, "practical dynamics of stellar systems" attracted the attention of researcher and gave valuable information about the space-kinematic structure of our stellar system and other stellar systems analogous to it. This includes: space distribution and stellar motion of different physical types and star clusters; characteristics of rotation of the galaxy; density distribution of substance in both the galastic plane and outside it, obtained by dynamic methods, etc. The most numerous and resultant in this area were the works of P. P. Parenago.[2]

How closely kinematic investigations led to the deepest questions of dynamic evalution of the stellar system was shown by the later works of Parenago. One of them (1954) permitted him on the basis of studying purely (it would appear) kinematic characteristics of a subsystem of short-period cepheids to conclude the presence in the galaxy of an effective mechanism of irregular forces ("gravitational collisions"). This conclusion and, thus, the conclusion of the relatively small value of relaxation time of the galaxy as compared

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[1]Pavel Petrovich Parenago was born in 1906 and from 1933 to the end of his life he was a Professor of the Moscow University; from 1953 he was a Corresponding Member of the Academy of Sciences of the USSR, awarded two Orders of Lenin. His main area of study was stellar astronomy, especially systematic investigations of variable stars (from 1922) and stellar-dynamic investigations; a great contribution to astronomy is his theory of light absorption. Parenago conducted extensive pedagogic work and educated many young scientists.

[2]See the survey in the collection "Historical Astronomical Investigations," No. 7, M., Fizmatgiz, 1961.

to the assumed value of the order (of 10^9 years instead of 10^{13}-10^{16} years) followed from Ogorodnikov's detection of a noticeable number of cepheids with speeds higher than "parabolic."

Investigations of kinematic character provide a basis for evolutionary and cosmogonic conclusions in which consideration of a system of stars as a totality of material particles (and further, as a sequence of kinematic distinguished subsystems) leads to sufficiently defined and grounded conclusions of the evolution of stars as physical bodies, and not simply "material particles" (G. Ya. Rootsmyae, 1959, 1961).

Important data of a structural and dynamic character about the distribution and motion of matter outside the galactic plane were obtained in works of P. P. Parenago, G. G. Kuzmin (1950's), Kh. Eelsalu (1958, 1961) and others. Various questions of the kinematics of objects of different subsystems were examined in these years by N. M. Artyukhina, K. A. Barkhatova, R. M. Dzigvashvili, D. K. Karimova, L. V. Mirzoyan, Ye. D. Pavlovskaya, A. Ya. Filin, A. S. Sharov and other authors.

Questions connected with galactic rotation led directly to the unification of results of kinematic theory and radio astronomy (dependence of the speed of rotation on distance to the galactic center, question about position and movement of spiral branches, in particular about direction of rotation). The first steps in study of the spiral structure of the galaxy according to radio observations were taken by P. P. Parenago (1955). After him followed I. L. Genkin, in 1962 introducing into consideration the K-effect – the relatively unstudied phenomenon of systematic radial motions of substance in the galaxy.

Attempts to remove contradictions between optical and radio observations of spiral branches later led Ye. D. Pavlovskaya and A. S. Sharov and simultaneously Yu. P. Pskovskiy (1965) to conclude the presence in the galaxy of more than ten spiral branches.

Examining the conditions for preservation of the spiral structure for a rotating galaxy, B. A. Vorontsov-Vel'yaminov (1955) concluded that the area of spiral structure approximately corresponds to the zone of "solid body" rotation of the stellar system. More detailed studies of law of galactic rotation were carried out at the beginning of the 1950's by P. P. Parenago and G. G. Kuzmin, and the reliability of the apparatus they employed was investigated later by A. S. Sharov, A. Ya. Filin and others. A radical improvement of the method of studying galactic rotation by radio observations (by means of calculating the whole contour of the radio line, and not only the position of its maximum) was made in 1962-1965 by T. A. Agekyan, Ye. V. Klosovskaya, I. V. Petrovskaya and B. I. Fesenko.

Considerable confusion and, moreover, error in the problem of the direction of rotation of galaxies appeared as a result of persistent shielding of Lindblad's hypothesis of "unwinding." In accordance with his own spiral structure theory Lindblad affirmed that the direction of rotation of galaxies coincides with the direction of the spiral branches.

The influence of the ideas of Lindblad meant that in Soviet literature for approximately a decade (from middle 1940's to middle 1950's) ruled an incorrect concept of the direction of rotation of spirals. In view of this, it must be said that criticism of the ideas of Lindblad, on a new stage substantiating the point of view of Slipher-Hubble, was heard first in our country (F. A. Tsitsin, D. Ye. Shchegolev, 1955) and only later abroad G. de Vaucouleurs, 1958).

One of the interesting questions of the general structure of the galaxy is the large-scale distribution of masses. On the basis of analogy of the galaxy with the Andromeda nebula, Parenago apparently first doubted the reality of the considerable relative mass of the nucleus of the galaxy (up to 60% of the total mass of system). Such a value was repeatedly obtained earlier using Oort's model of the galaxy (uniform spherical nucleus in a uniform oblate spheriod).

Pavel Petrovich
Parenago
1906-1960

Further investigation established the fictitious character of this appraisal, confirming thereby the validity of Parenago's opinion (A. M. Mikisha, F. A. Tsitsin, 1957).

A series of new results in the study of structure and dynamics of systems of "supergalactic" scale was obtained by G. M. Idlis, Z. Kh. Kurmakayev and T. B. Omarov in 1963, and in the field of study of kinematic-dynamic characteristics of the metagalaxy by K. F. Ogorodnikov (1952).

Questions of kinematics and structure ("practical stellar dynamics") and the works dedicated to it are so numerous and manifold that our survey cannot even claim a complete enumeration.

The Sun's Motion in the Galaxy and the Galactic Orbits of the Stars

Even in the middle 1920's V. G. Fesenkov and K. F. Ogorodnikov published a cycle of works of kinematic character about the sun's motion. This question later repeatedly was solved on even richer material of observations. A development of this subject was the

problem of the galactic orbit of the sun and other stars.

It is impossible not to note the work of P. P. Parenago about the sun's galactic orbit (1939). It was essentially the first investigation of the question, which possibly will have a practical value. This will happen if the considerable role (presented as fully possible) of replacement of "times of galactic year" and "space climate" along the orbit of the sun in the geological, thermal and biological sides of life of the earth will be clarified. If assumptions expressed on this count by certain researchers will at least in some measure turn out to be true, the problem of study of the sun's motion in the galaxy will become one of the fundamental problems of all contemporary science.

We can remember as an example that O. Yu. Shmidt considered the galactic solar motion a factor of fundamental cosmogonic value. A shift of the sun in the galaxy certain scientists connect with ice formation and geological processes of great temporary scale and with systematic change of intensity of cosmic radiation on the earth (perhaps the most important factor of biological evolution). A shift of the sun in a region seized by "explosive activity" of the nucleus of the galaxy and simply approach to a zone of relatively high frequency of bursts of supernovae also could have extremely important consequences for the earth as a celestial body and all the more so for its biosphere.

The sequence of approaches in consideration of this question appeared rather clearly, although it does not always correspond to their distribution in time. From the first results which approximated the sun's motion by the Kepler ellipse (P. P. Parenago), through investigations considering in some measure the dispersivity of mass in the galaxy (presence of mass and outside central nucleus), the path goes to works solving the same question within the bounds of the celestial mechanics approach (A. G. Pirog, 1941; later V. K. Abalakin), and further to the investigation of P. P. Parenago, who returned to consideration of this problem even at the beginning of the 1950's when he arranged his improved theory of galactic potential.

A cycle of investigations of galactic orbits of stars was conducted by R. M. Dzigvashvili, who expanded results of P. P. Parenago. The results of Dzigvashvili include the theory of orbits in Kuzmin's model of the galaxy (1958), and also obtaining the distribution function of elements of galactic orbits from the distribution function of stellar speeds (1961).

Future researchers of the problem of the galactic orbit of the sun probably should consider the dynamic nonstationarity of galaxy and the large-scale cosmogonic processes in it (transformation of dust and gas into stars); explosive phenomena of general-galactic scale, the value of which for stellar systems of galaxy type becomes all the more clear in recent years; irregular forces, and apparently collective effects of the type of plasma oscillations in "stellar gas" as a factor of change of the solar orbit; evolution of chemical composition of substance of the galaxy; dynamic peculiarities of the initial state and thermodynamic properties essential for the galaxy and similar systems; connection of the galaxy with other stellar systems and with the metagalaxy.

Irregular Forces As a Factor of the Evolution of Stellar System

In the middle 1930's in our country ideas were expressed which became later conventional elements of the conception of the dynamics of stellar systems. It touched on factors determining dynamic structure and evolution of stellar systems, the time scale (characteristic time of essential evolutionary transformation of galaxy and analogous systems – relaxation time). These ideas belong basically to V. A. Ambartsumyan.

In spite of the considerable role of basic ideas of the molecular-kinetic theory in formation of the dynamics of stellar systems, consideration and methods of this type were used within the bounds of the idea of the negligible role of "collisions" in the stellar system. Thus, the systems of "irregular forces" appearing during the approaches of objects were not considered (term of K. Schwartzschild). Corresponding appraisals were obtained by

J. Jeans and K. Sharl'ye even on the dawn of development of the dynamics of stellar systems – in the second decade of the XXth Century. They came to the conclusion that mutual approaches of stars are extremely rare; the relaxation time of the stellar system should be approximately 10^{14}-10^{16} years.

This conclusion, obtained for a stellar system of the type of our galaxy, ruled so strongly among astronomers that "irregular forces" were disregarded without discussion not only in questions connected with dynamic evolution of the galaxy, but also in examining stellar systems very different from our galaxy.

The error of the idea that the role of "gravitational collisions" was immaterial was uncovered by V. A. Ambartsumyan (1937, 1938), who showed that this mechanism is more effective by a factor of an order during the disintegration of a dispersed star cluster than the strongest of those examined earlier (B. Bok, United States). This again attracted attention to irregular forces in general, and to the problem of relaxation time in particular.

Further development of theory led to an understanding of one new and important, although, one would think elementary, circumstance. Namely, at the beginning of the 1950's L. Spitzer (United States), A. I. Lebedinskiy and others the fact that the relaxation time of the galaxy can be much less than was earlier obtained in theory if one considers the concentration of part of the substance of the system in massive clusters (not necessarily stellar). This could be gas-dust clouds, hypothetical superdense "prestellar bodies" (D-bodies) (V. A. Ambartsumyan), bodies experiencing gravitational collapse in the past, and others. If a system consists of bodies of different mass, then even a quantitatively insignificant "impurity" of massive bodies can sharply reduce the relaxation time of the system. Thus, if at least 10% of the mass of stellar system is concentrated in condensations with mass 10^{6}-10^{7} that of stellar, the relaxation time of the system turns out to be 5-6 orders less than obtained earlier. For the galaxy instead of 10^{14} years 10^{9}-10^{8} years is obtained, which is already comparable with the "galactic year."

Although it is still not very clear whether or not everything in the galaxy of massive condensations of substance is sufficient to decrease relaxation time at least to a value of the order of 10^9 years, realization of the possible role of the "effect of accumulations" opened before the dynamics of stellar systems unexpected prospects. For the first time it was possibile to explain the "basic paradox of dynamics of stellar systems": the observed fact of the existence of almost equilibrium velocity distribution, close to the most probable in the apparent absence of the mechanism of transition of a system to this state (relaxation).

K. F. Ogorodnikov, assuming that the mechanism of effective relaxation in galaxies exists, constructed the theory of a stellar system and obtained results which compared well with observations (dynamic classification and evolutionary diagram embracing stellar systems of all basic types; see the monograph "Dynamics of Stellar Systems," 1958, and a series of articles). K. F. Ogorodnikov used the circumstance that the presence of an effective mechanism of relaxation signifies the small mean free path as compared to the characteristic size of the system. Consequently, such a system is rightfully examined as a continuous medium. To study the dynamic structure and evolution of the stellar system represented by such a model, K. F. Ogorodnikov used statistical mechanics and hydrodynamics of gravitational gas. Another initial point of Ogorodnikov's conception is the assumption of dynamic immateriality – for study of a system – its external region ("corona"), containing a relatively insignificant part of the general mass and so rarefied that here the idea of a "macroscopic element of volume" already loses meaning ("physically infinitesimal volume," "physical point," according to the terminology of statistical physics and thermodynamics).

Among the most interesting results of Ogorodnikov's the possibility which he observed for the existence of a figure of galactic equilibrium in the shape of a strongly elongated triaxial Jacoby ellipsoid. This conclusion signifies the possibility of the actual existence of "needle-shaped" galaxies among the observed "spindle-shaped," which without exception had all been considered as disk-like figures of

of rotation visible from the "rib." Apparently, the possibilities of interpreting structures of the "cross connection" type in intersected galaxies are opened here.

In the theory of Ogorodnikov central condensations in stellar systems and the annular structures observed for a number of galaxies find a qualitative explanation. Although his method carries a certain conscious risk (inasmuch as the initial assumption about the existence of a mechanism of effective relaxation is not fully proven, and perhaps will turn out to be erroneous), the results present one of the most interesting constructions of Soviet dynamics of stellar systems.

Solution of the "basic paradox of the dynamics of stellar systems" recently was sought in calculation of the effects of "collective interaction" of stars, analogous to the interaction of particles in plasma. One of the pioneers in this region was L. S. Marochnik. However, the analogy between "stellar gas" and plasma by far is not complete. This leads to considerable difficulties in theory and leaves place for suspicion that the solution to the paradox does not lie on this path (assuming acknowledgement of the presence of the actual paradox, just as, for example, in the conception of K. F. Ogorodnikov).

The nearest in spirit to the concepts of Ogorodnikov is a group of works of V. A. Antonov. These studies are based in the end on the same assumptions as the works of Ogorodnikov. Of importance in these works is, in particular, the first strict (method of Lyapunov) analysis of the stability of stellar system from the point of view of the hydrodynamic theory of stability (1960). Among Antonov's concrete results is the interesting conclusion that for stability of a spherically symmetric model of a stellar system only disturbances which do not affect the spherical symmetry are "dangerous" (1962).

The result is significant; it establishes the presence for a stellar system of only <u>relative</u> maximum entropy (1962). This conclusion is connected with the conclusion that there is no maximum statistically

equilibrium state for a stellar system, founded on statistical and mechanical arguments. The last circumstance extraordinarily complicates the general problem of dynamic evolution of a stellar system as compared to the usual problems of statistical physics. Redistribution of stars in a space of speeds (energy) due to the action of irregular forces involves reconstruction of the system in a space of coordinates, i.e., and change of the field of regular forces.

The dynamic evolution of a stellar system in such general formulation of problem — taking into account the existence and mutual influence of the effects of evolution under the action of both irregular, and regular forces — was first studied by G. G. Kuzmin in 1961-1963. The outlook is apparently that in the solution to this problem a following step can be made in detailing and refining the above picture of the evolution of a stellar system. But the mathematical difficulties here are especially great. The use of high speed computers would help to overcome them.

Detailed Investigation of the Evolution of a Stellar System Under the Action of Regular and Irregular Forces

Investigations of mechanism of irregular forces also go back in our country to the works of V. A. Ambartsumyan (1937), who returned to this question in connection with the problem of a "time base" of a galaxy, deciding then in favor of a "long scale" — of the order of 10^{13} years or more (J. Jeans and others). Its acceptance was based on the (considered proven) statistical equilibrium of distribution of the totality of binary stars with respect to energy. Together with the initial appraisal of relaxation time of this totality (order of 10^{13} years) this led to the conclusion that the age of the galaxy exceeds 10^{13} years. (Such arguments in the strict sense are valid only for systems usually examined in statistical physics, and, as a rule, having a fundamental possibility of reaching the state of statistical equilibrium. They are somewhat less defined in application to a stellar system for which generally the state of statistical equilibrium is unattainable. This practically ignores

the distinction of a stellar-dynamic system from a statistical-physical system stressed later by Ogorodnikov.)

It is necessary to note that the age of the galaxy was exaggerated again because the source of stellar energy was considered to be the process of annihilation of substance in the mineral resources of stars, much more effective in power yield than any processes of thermonuclear fusion or radioactive decay.

In this situation appeared the results of V. A. Ambartsumyan on estimating the time base of dynamic evolution of the galaxy, sharply disharmonizing with conventional ideas. Analysis of distribution of components in binary systems led Ambartsumyan to conclude that the totality of such systems still did not reach the state of statistical equilibrium, although for this, according to his appraisal, an interval of time of the order of 10^{10} years would be sufficient, i.e., several orders less than the assumed age of the galaxy. Ambartsumyan asserted his conclusion in discussion with one of the highest authorities in this area – J. Jeans.

The position, however, was further complicated by the fact that at that time certain of our authors, not being specialists-astronomers, tried to fix the idea of the "long scale" as the only possible materialistic point of view (apparently only because obvious idealists and direct fidiests intensively speculated on a "short scale").

Undoubtedly, the work of Ambartsumyan played a large positive role, paralyzing the tendency to fix materialism to the historically doomed, "long scale."

At the same time the result of Ambartsumyan, although correct, was esstentially, as we now see, not sufficiently grounded. The argumentation of this work contains prerequisites which are arbitrary from a contemporary point of view (for example, uncondltonal acceptance of the possibility of statistical equilibrium between the number of single and binary stars in a system; acceptance of a concrete – Maxwell-Boltzmann form of a statistically equilibrium distribution function of pairs by energy, etc.). However, it is necessary to

ascertain that in general the deficiencies and error, of Ambartsumyan's work led to an illegally expanded interpretation of results, the boundaries of validity of which could be ascertained only in the future.

Subsequent development of theory (L. E. Gurevich, B. Yu. Levin, 1950, and others) led to more precise devinition of Ambartsumyan's results. However, investigations in this area are still far from completed. In general two or three small articles by V. A. Ambartsumyan 1936-1938 became actually a new step in development of the dynamics of stellar systems on the whole and already established it in our country on a level of "world standards," which always is ensured only by leadership in a noticeable and important division of the science.

Dynamics of a Stationary Galaxy

The following stage passed by Soviet stellar dynamics turned out to be absolutely independent from Ambartsumyan's cycle of investigations. The greatest Soviet specialist in the area of stellar astronomy P. P. Parenago arrived at important stellar-dynamic results on the other hand, proceeding from a purely kinematic circle of ideas and "practical stellar dynamics."

And in prewar and the first postwar years stellar-dynamic investigations of P. P. Parenago were concentrated basically in stellar kinematics ("parctical dynamics of stellar systems"). This direction, as already was said, became for Parenago the source of information about the structure of the galaxy, about distribution and movement of different types of stars in it. However, results of the work frequently were not fully comparable among themselves. The cause was a lack of a logically consistent stellar-dynamic conception from which they originated.

Above it was noted that in the dynamics of stellar systems essentially there still is no logically consistent system of theoretical foundations. Although it is obvious that, let us say, the theory of a nonstationary system is more general than the theory

of a stationary system, it has never been clear where one passes the boundary of validity of the "stationary theory." Considerations of purely mathematical character (extremely great complexity of the "nonstationary theory") push theoreticians to grasp as great a region of facts as possible within the framework of the "stationary theory."

There is basis to suspect that in very many cases we in "practical stellar dynamics" operate by ideas and methods of the stationary theory, etc., far from the borders of its validity.

In the works of P. P. Parenago an exceptional caution is characteristic in interpretation, in appraisal of the real accuracy of results of practical dynamics of stellar systems, which formally (by appraisal of internal error) seemed frequently very reliable. This appeared also in his development of the theory of galactic potential.

The theory of the stationary galaxy was basically constructed by Oort even at the end of the 1920's. Parenago, developing this theory (1950, 1952), obtained a new fundamental result: an analytic expression giving in evident form the potential everywhere in the equatorial plane of a stationary stellar system.

On the basis of this result a series of important corollaries was obtained (new "theoretical" model of the galaxy theory of galactic orbits conclusion about stability of circular orbits in the equatorial plane of the galaxy and others). In particular, Parenago constructed the galactic orbit of the sun.

Considerable contribution to the development of the theory of galactic potential was later introduced by G. M. Idlis (series of articles and the monograph "Structure and Dynamics of Stellar Systems," 1961). He originated from the idea of construction of a model of a stellar system with Parenago's potential for two maximum cases, "embracing reality" and also analytically very simple: spherical and flat stellar systems. It was essential that results, exceeding the limits of accuracy of observations ("radii" of models, mass,

character of distribution of potential and density as a function of distance from center, etc.), turn out to be relatively very close for these two models.

For both Parenago and Idlis the density of substance in the model at sufficient distance from the center turned out to be negative. Parenago assessed this as a natural that Parenago obtained this result within the bounds of an attempt at semiempirical propagation of his theory of galactic potential into regions outside equatorial plane of a stellar system. But Idlis in the spherical model with the Parenago potential did not take "along the way" any steps which could be incompatible with the initial prerequisites of the theory of a stationary galaxy. Thus, this result in Idlis' work in the end emanated from basic initial prerequisites of the general theory of a stationary stellar system.

G. M. Idlis was inclined to interpret the paradoxical conclusion about negativity of density at sufficiently great distances from the center of a stellar system as evidence of the limitedness of stellar systems (and not as the fault of theory). For the "critical" distance Idlis, "in accordance with requirements of the physical meaning," proposed the density identically equal to zero, considering this as a real property of a stellar system.

However results of Idlis apparently indicate more the deficiencies in prerequisites of the actual theory of a stationary stellar system. Actually, among these prerequisites neighbor on one hand the assumption of stationarity of a system, and on the other Schwartzchild's assumption of ellipsoidal (having "Maxwell's tail") velocity distribution. It is obvious that these two assumptions are incompatible for any system with finite mass; moreover, compatibility by far is not automatically ensured even for unlimited mass of a system. In any case, a stationary model of a finite system with Schwartzchild velocity distribution, in which density at a finite distance from the center turns into zero is intrinsically self-contradictory. In such a system a "spreading" of the border is obviously inevitable, signifying the system is nonstationary.

An essential deficiency of the classical theory of a stationary galaxy is affirmation of the equality of R- and z-axes of the velocity ellipsoid (observations show that the z-axis is not equal to the R-axis and is the least of the three). Investigations and attempts to surmount this contradiction lead to analysis of the most general mechanical properties of a stellar system (for example, number, role and appearance of integrals of motion of an individual star in a stellar system). Fundamental results in this direction in our country were obtained and developed from the beginning of the 1950's by G. G. Kuzmin. He, in particular, offered the most satisfactory expression of the third (after integrals of energy and angular momentum) integral (more exactly, quasi-integral) of motion, making it possible to remove the above contradiction of theory with observations. Interestingly, the velocity ellipsoid outside the galactic plane turns out to be "inclined" to it. The "semitheoretical" model of the galaxy built by G. G. Kuzmin on the basis of his theory, was the basis of certain investigations of other authors (I. L. Genkin, R. M. Dzigvashvili).

Works of I. L. Genkin in 1962, 1963, which examine different aspects of the theory of a stationary and nonstationary stellar system with Schwartzchild velocity distribution, were influenced by the ideas of G. G. Kuzmin, certain results of which he generalized. The influence of ideas of Kuzmin on certain other researchers of models of self-attraction systems is undoubted (Yu. I. Veltmann, 1961; S. A. Kutuzov, 1962).

Questions connected with problems of different dynamics (including general mechanical) properties of a stellar system, in particular integrals of stellar motion, in the last 8-10 years were the subject of a series of works by K. F. Ogorodnikov, G. M. Idlis and other authors.

It is necessary, however, to note that recently "leadership" in development of the problem of integrals of motion has left the Soviet Union. This is explained by wide use of high speed electronic computers abroad in solving this range of questions, which permitted

theoreticians (G. Contopolos in Greece and others) to probe a series of important statistical and mechanical properties of a stellar system.

Detailed Investigations of the Effects of Irregular Forces in a Stellar System

The insufficiency of the mechanism of regular forces for explanation of the basic properties of a stellar system and promise of detection of an effective mechanism of irregular forces were revealed in works dedicated to different aspects of the problem of nature and effectiveness of irregular forces in stellar systems of different type.

Actually, as was noted, within the bounds of the theory of a stationary stellar system without irregular forces the fact of typically statistical-probability velocity distribution of stars looks already paradoxical ("basic paradox of the dynamics of stellar systems" – K. F. Ogorodnikov). Therefore many-sided investigations of the mechanism of irregular forces from both a quantitative and qualitative side continues to attract the attention of many specialists, in particular in our country.

Already in the elementary act of irregular interaction – "gravitational blow" of two bodies in a regular field of gravitation of the galaxy-basic tendencies of the evolution of a stellar system under the impact of irregular forces are revealed. (Exchange of energy of two bodies while maintaining its full value leads in some cases to a decrease in the energy difference, in others to an increase. In the last case the body passes energy onto an orbit on the average smaller than the initial. Here part of the substance tends to "settle" toward the center of the system. The second body either passes into an orbit of "larger size" – tendency to an increase of density on the "periphery" of the system, to an increase of the size of the system, or completely abondons the system – tendency to dissipation.)

The construction of a quantitative theory of processes revealed in this elementary consideration composes the problem of division of the dynamics of stellar systems, studying the effects of irregular forces in a stellar system.

The biggest value on first stages of the investigation of this problem belongs to results revealing the existence of effects which are general for any stellar systems. Such qualitatively new sides of irregular evolution includes the effect noticed by L. E. Gurevich and B. Yu. Levin (1950). It is that the "irregular evolution" of a stellar system should take place in the preservation of the total energy of a system, in spite of the dissipation of stars from it.

Actually, an exchange of energy between stars in a field of irregular forces should occur as a rule in minute portions, since the number of distant encounters is overwhelmingly great as compared to the number of near encounters. Therefore if a star finally obtains energy sufficient for its "evaporation" from a system, then with overwhelming probability it is possible to affirm that the magnitude of energy of this star only very insignificantly exceeds critical value. "On infinity" the energy of such a star due to the property of "parabolic" motion turns out to be close to zero. Consequently, dissipating stars remove from a system a very insignificant amount of energy. This means the evolution of a system even in the presence of a dissipation with a high degree of accuracy can be considered as occurring at constant energy.[1]

Discovery of this property of a stellar system, evolving with dissipation of its own members due to the action of the mechanism of irregular forces, permitted L. E. Gurevich and B. Yu. Levin to trace

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[1]This is valid only on the assumption that there is no energy "swing" due to the transition of part of the thermonuclear energy liberated in stars into the energy of stellar motions and positions. The influence of this factor usually is absolutely disregarded, but essentially its role has been practically uninvestigated and could be quite considerable.

the evolution of a stellar system "from beginning to end."[2] A simplification of the problem was that the evolution of a system was modelled by the evolution of a certain "characteristic volume," possessing average values of the characterizing system of parameters – density of energy and substance, dissipation rate, etc. It turned out that evolution of the examined model occurs with progressing condensation of the central region, decreasing in mass, and in an accelerating rate which is completed by practically complete scattering of the system after a finite time.

The rational grain in these conclusions was, as later investigations permit thinking, exactly the conclusion about progressing and accelerating condensation of the central part of a system with a decrease of mass of the condensed nucleus. In a model of a system of gravitational material particles dissipation can continue up to the state when the only remaining thing in the system is a sufficiently close stellar pair. Taking into account the effects of the relativistic theory of gravitation collapse of the compressed nucleus of a stellar system turns out to be possible (Ya. B. Zel'dovich, 1964).

Roughness of the assumption (rather usual) about the representability of the evolution of a system by the evolution of a characteristic volume did not permit in the Gurevich-Levin model and in analogous models showing any characteristic traits of evolutionary reconstruction of the external region of a system.

Toward the end of the 1940's and beginning of the 1950's appeared a cycle of works, partly joint, by L. E. Gurevich and A. I. Lebedinskiy, which is important for understanding the development of basic ideas and presentations of the dynamics of stellar systems. In their works problem about the dynamic evolution of a stellar system was placed more broadly than is usually done in the dynamics of

[2]Analogous work was carried out in the United States after 14 years.

stellar systems, and was decided with the help of a richer "physical instrument set." Thus, serious attention was turned to the stellar dynamic role of the prestellar stage of existence of a future stellar system. In view of the continuing process of star formation this prestellar stage was essential not only for the epoch directly following the transformation of a considerabe part of prestellar substance into stars. Continuation of the process of star formation can play a fundamental role, affecting the most important dynamic properties and characteristics of stellar systems. In particular, this leads to the complicating factor that a stellar system like our galaxy turns out to be "fundamentally not quasi-static." Subsystems of stars of various age are statistically unbalanced by themselves in various degree and moreover have different "temperatures" (dispersion of speeds) in a given region of space.

For a model not having these complicating circumstances L. E. Gurevich made thermodynamic considerations and obtained a general picture of the dynamic evolution of a stellar system. The basic features of this picture are determined by the fact that on the prestellar stage (gaseous dust substance) evolution of the system occurs in a flattening of the system, accompanied by considerable loss of energy due to the nonelastic character of gas-dust cloud collisions. Gravitational energy of the system is turned into kinetic energy of gas, thermal energy of dust particles and, further, disperses in the form of thermal radiation of these particles.

After the transformation of gas into stars, the "collisions" become almost absolutely elastic, since they lead to stellar encounters. Evolution occurs with the preservation of the full mechanical energy of the stellar system and loss (dissipation) of its angular momentum with the stars flying from the system. Very flat in the beginning, the stellar system starts to thicken. In the central part a growing nucleus forms. Torque is outside stars, from which a very flat expanded equatorial disk of the stellar system gradually is formed. Rotation of the central part is delayed and approaches "solid-body," characterized by constancy of angular velocity at different distances from the center of the system.

A. I. Lebedinskiy further showed that in sufficiently contracted stellar system the effect of gravitational instability of the "stellar gas" should appear, which is also thermodynamically profitable. The disk breaks up into star clouds with dimensions of the order of hundreds of parsecs. As the system thickens (due to growth of the dispersion of speeds) this process ceases to be accompanied by an increase of entropy and turns out to be "forbidden" (central parts of spiral galaxies, elliptic galaxies).

This conception also has a number of weak points. This includes, for example, insufficient validity of the application of thermodynamic consideration, in particular the principle of maximum entropy in the "equilibrium" state, to the system for which the validity of thermodynamics (in the usual form) is not self evident; confusion with the idea of "volume" for stellar system – one of the fundamental variables of theory, etc. Nonetheless the studies by L. E. Gurevich and A. I. Lebedinskiy are very important from the ideological side, interesting from the point of view of obtained results a pioneer in the particular methodology (wide application of the thermodynamic method in the dynamics of stellar systems).

Detection of one important general dynamic effect connected with dissipation of revolving systems led T. A. Agekyan at the end of the 1950's to the conception of dynamic evolution of stellar systems. The initial point was that dissipation of masses from an examined volume element of a revolving system should occur chiefly in a direction coinciding with the direction of the velocity vector of the given volume element participating in systematic rotation of the system. Therefore specific angular momentum lost by system during dissipation can essentially exceed the average moment of a mass unit of the system.

Taking into account this effect, and also constancy of energy of a system T. A. Agekyan starting from 1958 arrived at a number of fundamental, and apparently in considerable degree real results in

in the theory of dynamic evolution of a revolving stellar system.[1] Within the bounds of this theory he showed that due to the effect of excessive loss of torque the totality of revolving stellar systems is divided into two qualitatively different sequences depending upon the initial compression (c/a) system (c — minor semiaxis, a — major semiaxis). When the initial value of c/a exceeds 0.74, evolution of the system is accompanied by ever greater "spherization." When the initial value of c/a is smaller than critical, the system in the process of evolution is all the more flattened.

The fact that the calculated critical value of compression turns out to be close to its value observed for the most compressed elliptic galaxies is significant. Moreover, in the theory of T. A. Agekyan there is no such weak place as in the conception of Gurevich and Lebedinskiy it is, although very tempting, not sufficiently well grounded to use the apparatus of thermodynamics in the dynamics of stellar systems.

It is impossible not to note, however, the defined limitation of Agekyan's conclusions that the "flat sequence" of stellar systems (which he obtained), in contrast to the spherical cannot be simply identified with a certain corresponding sequence of observed galaxies. Formally Agekyan's of "flat sequence" would have had to have the appearance of spheroids flattening with time, whereas in galaxies of the corresponding observed sequence along with a flat "lens," apparently there always is a central thickening. Undoubtedly, this deviation from observation is because Agekyan used the above "method of the characteristic volume." With such an approach to the system as a whole properties and evolutionary tendencies inherent to that place in the system which coincides with the position of the "characteristic volume" are inevitably recorded. As was noted above,

[1]They are given in a number of articles and are partially summed up in the book "Course of Astrophysics and Stellar Astronomy." M., Fizmatgiz, 1962.

in this case features of the evolutionary process, even those dominating in certain other parts of the volume of the system, i.e., qualitatively important for the idea of the evolution of : vstem as a whole, can be lost.

In this case Agekyan noted that whatever the properties of the characteristic volume were not (i.e., independently of whether they determine if a system belongs to a flat or spheric sequence), and in the case of a system of a flat sequence the tendency to thicken in its central zone should predominate. Somewhat exceeding the formal framework of developed theory, and thus, expanding it, Agekyan qualitatively obtains farther reaching results: the system of a flat sequence with a nucleus is essentially identical to observed spiral galaxies, the flat component for which has compression exceeding critical, and in the center is the nucleus.

It is necessary to remember that separation of the evolutionary sequence of galaxies into two groups, which could be compared with Agekyan's flat and spheric sequences, was somewhat earlier obtained by K. F. Ogorodnikov, who originated from essentially other, and undoubtedly more problematic prerequisites of his own "synthetic method." Such stringent requirements which should satisfy the system subordinated to Ogoodnikov's theory include in the first place the very strong, perhaps even not actually realizable, condition of representability of the galaxy (stellar system) by a model for "compressible liquid." This requirement, as was already said, is equivalent to Ogorodnikov's condition of insignificance of the "mean free path" of a star in comparison with the characteristic dimensions of the system.

Agekyan's concept is satisfied by less stringent requirements on the system. It is obvious that Agekyan's and Ogorodnikov's concepts (as also that of Gurevich and Lebedinskiy) are not mutually exclusive.

As separate elements of his own concept Agekyan obtained a series of important results. Included are an appraisal of the probability of an encounter with an assigned change of absolute velocity (1959);

distribution function of stellar velocities, definitizing the Schwartzchild distribution, and appraisal of the dissipation rate of a stellar system (1959); calculation of the effect of multiplicity of encounters (1961) and others. Obtaining, for example, a more exact velocity distribution function made it possible to estimate quantitatively the degree of accuracy of ideas about dissipation without loss of energy, etc. V. S. Kaliberda (1964) made studies in this area.

The problem of the evolution of a stellar system under irregular forces even now is the center of stellar-dynamic interests of Agekyan and his colleagues (I. V. Petrovskaya, V. S. Kaliberda).

As recent publications showed (1962-1965) there are rich possibilities here for new interesting conclusions. After all, as yet there is no complete theory of even the simplest (spherical) stellar system to which there are no objections. This is the object of especially intense study on the part of Agekyan and his colleagues.

Agekyan's scheme has certain points in common with the evolutionary diagrams of Gurevich, Lebedinskiy and Ogcrodnikov, who first clearly divided the evolutionary effects of regular and irregular forces.

According to him the development of stellar system starts from a state generaly unbalanced with respect ot both regular and irregular forces. Further stellar motion of a system in a self-consistent regular, initially nonstationary field of gravitational forces due to a "mixing" process (A. Punankare, N. S. Krylov) approaches a state stationary in a regular field.[1] Then the mechanism of irregular evolution begins to act, putting the system into a state

[1]An important work of G. G. Kuzmin must be noted (1957), which establishes that even the initially significant nonstationarity of the stellar system in a regular field due to the "mixing" effect (without considering irregular forces) disappears through a time of the order of several revolutions of the system, and in the system is established the state called "mechanical statistical equilibrium," detailed balance in the absence of "collisions."

of equilibrium with respect to the other and irregular forces (more exactly, quasi-equilibrium in view of the absence of the state of full statistical equilibrium).

Local stationarity is attained initially in the center of the system. From the center gradually spreads a region in which equilibrium is no longer local (analogously to local thermodynamic equilibrium), but "full" in the sense analogous to full thermodynamic equilibrium of the physical system as a whole. This state corresponds (asymptotically) to rotation of the system as a solid and constancy of the velocity dispersion ("temperature") of the whole region of "quasi-stationarity." A distinction of the state from strict equilibrium will be caused here by the factor of dissipation, which determines now all further evolution of the system. In accordance with the results of Gurevich and Lebedinskiy, agreeing with subsequent conclusions of Agekyan, "the region forming in the central part of the system, quasi-stationary as a whole, causes a thickening of the system in this place" ("Course of Astrophysics and Stellar Astronomy." Publishing House of Academy of Sciences USSR, 1962).

Such, in broad terms, is the picture of dynamic evolution of a stellar system, the last and, apparently, the most important features of which are revealed by T. A. Agekyan, but which would not have happened, of course, without the work and results of other Soviet students of stellar dynamics.

Work in the region of the dynamics of stellar systems in the USSR is headed by the Astronomical Council of the Academy of Sciences USSR through the Working Group in the Dynamics of Stellar Systems under the Council. For several years the Astronomical Council has orginized extraordinarily fruitful systematic conferences - seminars of the Working Group in the Dynamics of Stellar Systems. As a result of these conferences investigations in the USSR in the region of dynamics of stellar systems became more systematic and assumed an even more stable character.

Conclusion

Considerable achievements in the problem of dynamic structure and evolut.on of stellar systems at the same time show that the dynamics .. ..ellar systems is faced with a series of fundamental questions for which the solution has not been found or has only just appeared. The interests of scientists turn to the basic questions of foundation of the dynamics of stellar systems, analysis of its initial principles lying in its basis of general physical positions, their compatibility, agreement and sufficiency as a basis of stellar-dynamic theory. This appears in a number of works and publications of Agekyan, Idlis, Kuzmin, Ogorodnikov and others theoreticians.[1] The central problem is the question of construction of noncontradictory statistical mechanics of stellar systems in general, (K. F. Ogorodnikov, 1957). Further, above it was already noted that the assumption of an effective mechanism of irregular forces in a stellar system has still not been confirmed by observations; the causes of the clearly not accidental "step" structure (in distribution of density) discovered for star clusters (P. N. Kholopov, 1953) and later for clusters of galaxies (A. S. Sharov, 1959);[2] are absolutely uncomprehensible; confusions and discrepancies in the problem of boundaries in questions of interaction of galaxies are numerous (R. A. Saakyan, 1960); still darker is the question about the spiral structure – its genesis and development; many gaps are in the problem of dynamic activity of the "centers" of stellar systems which are of galaxy scale; in the last few years unexpectedly the problem of "relativistic gas from the stars" turned out to be pressing (Ya. B. Zel'dovich).

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[1]See "Bul. Abastumani Astrophysics Obs.", 27, 1962; "Transactions Astrophysical Institute of Academy of Sciences, Kazakh SSR," 5, 1965.

[2]Incidentally, the characteristic "step" distribution of stellar density was noted earlier by Herschel for the globular cluster 47 Tuc (1847), which the history of astronomy has absolutely forgotten (see A. I. Yeremeyev. The Universe of Hershel. M., publishing house "Nauka," 1966, p. 221).

In the most general approach, not limited by the framework of a mechanical model, the dynamics of a stellar system can be examined as statistical mechanics of a system of gravitational particles, not contained in some "vessel" or "thermostat" (in contrast to the physical setting of analogous problems). There is still a question about form and methods of calculation of gravitational influence on the system from the side of all remaining bodies of the universe interacting with it, not considered usually in the dynamics of stellar systems only for "simplicity."

Statistical mechanics of a gravitational system (all the more so having indefinite volume) does not yet exist. The problem of the volume of a stellar system (intimately connected with the question of the boundaries of stellar systems) also is not solved satisfactorily. Consideration of the presence and influence of external masses encounters huge difficulties (here we are in direct proximity with such dangerous difficulties as the "gravitational paradox," etc.). It is clear only that the previously used method of "considering" the external masses simply by disregarding them and consideration of a single autonomous system in infinite space is unsatisfactory and leads to internal contradictions and paradoxes in theory. Thus, considering it rightful during construtiom of a model of the galaxy to disregard the existence of all external systems (i.e., postulating disregard of the influence of these "sufficiently distant masses"), we arrive at a model in which even arbitrarily distant masses nevertheless exist and turn out to be an essentially determining property of the internal parts of the system. At the same time they are obviously less than those masses which we considered it possible to disregard in these "sufficiently distant regions of space..."

Against the background of this contradiction the conclusion about infinity of the mass of the stationary model of a stellar system seems no longer so serious. According to I. L. Genkin (1963), such a conclusion is inevitable for any stationary system with Schwartzchild velocity distribution; it is almost obvious that this result is valid for a stationary system with any "physically real" velocity distribution, with the necessity of possessing a "Maxwellian tail."

In stellar systems of the "biggest scale" we arrive at the most general stellar-dynamic problem" what are the laws of distribution of density and velocity and the dynamic evolution of stellar gas, filling with nonzero average density unlimited space? This problem goes far beyond the framework of contemporary statistical mechanics.

Much is vague with respect to the possibility and limits of using thermodynamic methods and thermodynamic theory and within the bounds of the usual setting of the stellar-dynamic problem.

In the future in the dynamics of stellar systems it will be necessary to exceed the framework of purely mechanical model of a stellar system as the totality of gravitational material particles and introduce into consideration factors of cosmogonic and physical character — presence and role in the stellar system of gas, dust and physical fields besides gravitational. It will be necessary to consider stellar evolution and bilateral interaction with the interstellar medium. Very desirable is the prospect of calculation of the possible role of the metagalactic ("initial") magnetic field (S. B. Pikel'ner, 1965), etc. In general the quantity and complexity of problems facing stellar dynamics promise a prolonged period of active development and progress. Enumeration of all these problems at the same time indicates those directions in which it is possible to expect the most important stellar-dynamic results. The most intense stellar-dynamic studies in our country and in the whole world are along these lines.